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EXECUTIVE SUMMARY

This report presents an analysis of the energy, emission, and safety implications of potential investments in the Upper Mississippi River and Illinois Waterway (UMR-IW) System. The U.S. Army Corps of Engineers (USACE) has identified 10 alternative improvements to the UMR-IW System. The most comprehensive improvement scenario (Alternative J) would result in: the construction of adjacent mooring cells at Locks 12, 18, 20, 22, and 24 on the Upper Mississippi River; the extension of guidewalls to 1,200 feet (with powered kevels) at Locks 14-18 on the Upper Mississippi River; the extension of Locks 20-25 on the Upper Mississippi River to 1200 feet; and the construction of new 1200-foot locks at Peoria and LaGrange on the Illinois Waterway. The other 9 alternatives encompass one or more of the above improvements.

The energy, emission, and safety effects of each alternative are estimated for 2015, 2030, and 2050 based on traffic forecasts developed by the USACE. For each alternative, USACE has projected waterway traffic levels in the "with-project" and "without-project" futures. The difference between the two estimates is the incremental or affected tons, which are the focus of this analysis. In 2015, USACE estimates that over 10 million tons of traffic will be affected under 6 of the improvement scenarios. By 2050, between 15.8 and 23.7 million tons will be affected under the same 6 scenarios. Although 17 commodity groups are affected by the improvements, agricultural products comprise over 85 percent of the affected traffic. In 2050, approximately 20 million tons of agricultural products will be affected by some of the proposed projects. This tonnage is equivalent to roughly 200,000 annual rail carloads.

STUDY APPROACH AND KEY ASSUMPTIONS

For purposes of consistency, this study uses the same traffic forecasts that were used in earlier phases of the UMR-IW study.[1] These forecasts are based on: <u>Waterway Traffic Forecasts for the Upper Mississippi River Basin</u>, by Jack Faucett Associates (April, 1997) and a detailed economic model described in: <u>A Spatial Price Equilibrium-Based Navigation System NED Model For the UMR-IW Navigation System Feasibility Study</u> (USACE, 1998).

Because of the commodities and distances involved, railroad transportation is the only feasible alternative to river movements. In this report, a comparison is made of the line-haul fuel efficiencies of rail and barge modes. Gathering or distribution movements by truck are not reflected in this comparison. If truck trip distances into rail and barge stations differ substantially, then combined truck-rail and truck-barge fuel efficiencies may differ from the direct modal estimates shown in this study.

Barge and rail energy comparisons are made on the basis of revenue ton-miles per gallon (RTMG). It is expected that both barge and railroad fuel efficiencies will be greater in 2015 than today, but the relationship will stay approximately the same. Manufacturers of marine diesel engines typically start with a partial or fully completed land-based engine and adapt it for use in a marine environment. Because of similarities in engine manufacturing and the uncertainties involved in technological forecasting, it seems reasonable to assume that the relative fuel efficiencies of the modes will be the same in 2015 as today.

<u>**Barge Fuel Use Factors**</u>. Barge RTMG factors have been obtained from Tennessee Valley Authority

1 A new traffic forecast was not included in the scope of work for this project. Using the same traffic forecast that was used in earlier phases of the UMR-IW study provides a consistent basis for evaluating the results.

(TVA) and the Corps. TVA data for 1995, 1996, and 1997 indicate that revenue ton-miles per gallon ranged from 306 to 320 on the Upper Mississippi River and from 259 to 312 on the Illinois River. In comparison, a USACE report projects that efficient 15-barge grain movements on the UMR-IW System could achieve 450-700 revenue ton-miles per gallon. Clearly, upper river fuel efficiencies are expected to be higher than historic values in the with-project scenarios because of lock and guidewall extensions and mooring cells. Thus, a value of 375 RTMG is used for barge movements on the upper river system. This value represents a compromise between the USACE=s lowest efficient movement estimate of 450 RTMG and the midpoint value of the TVA data set (about 300 RTMG). A value of 644 RTMG is used for the lower river system, which corresponds to the middle year of the TVA data range.

Railroad Fuel Efficiency Factors. A detailed literature review was conducted of railroad energy studies, including recent train performance simulations. In 1999, Gervais and Baumel published the results of several simulations of corn unit-train movements in 100- and 110-ton cars from Iowa to New Orleans and Tacoma, Washington. The reported RTMG estimates range from 554 to 664 for the Tacoma movements and from 688 to 802 for movements to New Orleans. Although the Gervais and Baumel simulations are referenced in this report, an extensive empirical analysis is presented based on 1989-1998 Class I railroad data obtained from the Surface Transportation Board (STB). Two statistical models of railroad fuel use are estimated from the data. Both models exhibit excellent statistical properties and predict RTMG values that are very close to actual values. The models are used to predict RTMG for each origin-destination movement, considering the railroads involved, the commodities, train service characteristics, and car weight factors.

Air Quality Impact Assessment. In the future, air quality regulations are expected to uniformly limit emissions per gallon of fuel from nonroad freight sources. The approach used in this study is to multiply the estimated difference in gallons of fuel consumed in the with-project and without-project scenarios by the emission rates per gallon. The cost or valuation of incremental emissions is a complicated issue that can be approached in several ways. In the first approach used in this study, the difference in emissions is multiplied by a unit cost of pollution compliance or abatement computed from an Environmental Protection Agency (EPA) report. The assumption is that railroads will keep emissions at the same level in the with-project and without-project scenarios, and in doing so will incur a compliance or abatement cost. If the incremental emissions are not abated or offset by reductions elsewhere, then overall emissions from nonroad sources will increase and there will be a cost to society that is not internalized by the transportation modes. In this case, incremental emissions of nitrogen oxides, particulate matter, and other pollutants will adversely impact human health, property, vegetation, and crops. The potential societal costs are estimated by multiplying the incremental emissions by a set of air pollution damage factors used by Federal Highway Administration in the Highway Economic Requirements System. In this approach, the health and property damage costs associated with increased levels of specific pollutants are accounted for. The estimates from the two approaches are not additive. Either railroads will keep nonroad emissions at the same level and incur a compliance cost, or the incremental emissions will result in air pollution damage costs.

Safety Data and Analysis Methods. Three categories of accident costs are analyzed: property damage, injuries, and fatalities. Without-project costs are based on railroad accident factors, while with-project costs reflect waterway accident data. The railroad accident data are derived from Federal Railroad Administration (FRA) reports and bulletins. Waterway accident rates and costs are derived from a previous study by University of Memphis. For each mode, a two-step analysis process is followed: (1) estimate the annual accidents, fatalities and injuries for the incremental traffic and (2) multiply the annual events by the applicable unit cost per property damage, fatality or injury. The fatality and injury unit costs reflect economic cost factors as well as the value of Alost quality of life.@ They reflect estimates of what people are willing to pay for improved safety. According to the National Safety Council, these Acomprehensive costs@

can be interpreted as Athe maximum amount society should spend to prevent a statistical death or injury.@

SUMMARY OF RESULTS

Estimated Railroad Revenue Ton-Miles per Gallon. As noted earlier, two statistical models were estimated from Class I railroad data. Model 1 estimates railroad fuel consumption as a function of way train, through train, and unit train gross ton-miles. It is used to illustrate how RTMG vary with type of train service. For 1998, the model predicts Class I railroad fuel consumption rates of 446, 352, and 193 RTMG for unit, through, and way trains, respectively. When these values are multiplied by the percentages of gross ton-miles in each train category, the predicted value of 379 RTMG is within 1 percent of the reported industry mean of 384 RTMG. Model 2 directly predicts revenue ton-miles per gallon as a function of the revenue tons per train, the tare tons per train, and the loaded trip miles. The model was tested by comparing predicted RTMG values to actual (reported) values for each railroad, for each year of the analysis period. The prediction error exceeded 10% in only 8 of the 90 cases. The 1998 prediction errors were less than 5 percent for the UP, BNSF, and IC (the primary railroads of interest in this study). The model was used to estimate values for a series of hypothetical movements. It predicted RTMG ranges of 309 to 605 for mixed freight trains and 349 to 682 for 75-car grain through/unit trains moving distances of 400 to 800 miles. The largest estimated value that does not violate the data range of the model is 735 RTMG for a unit train movement of approximately 1000 miles on the Illinois Central Railroad. In general, the high-end grain through/unit train estimates generated from the model overlap the lower end of the Gervais-Baumel RTMG range.

Estimation of Railroad Fuel Use for Incremental Movements. The origins and destinations and incremental tons were provided by the USACE. However, important railroad shipment information was derived from the 1998 public-use waybill sample, which was used to develop movement profiles for traffic originating in Business Economic Analysis (BEA) areas adjacent to the upper river system. The waybill sample was not used to forecast railroad traffic. Its was only used to describe current railroad shipment characteristics in the Upper Mississippi region. The primary characteristics of interests were: the percentage of tons moving in each level of train service, the number of cars in the shipment, the average load per car, and the average tare or light weight per car. The last three variables determine the revenue and tare weight inputs to Model 2. The percentages of railroad traffic moving in various waybill strata were used to partition affected river traffic into train service levels. In essence, the approach used in this study allocates the incremental tons in each commodity group to railroad shipment strata, then estimates the fuel consumption within each strata and sums or weights the results. The underlying calculations also reflect the railroads involved in the movements. In most cases, the sample waybill data reflect efficient railroad movement patterns. For example, approximately 80% of the farm products tons shipped from Iowa BEA areas to the Pacific Northwest moved in100-110 car blocks. Similarly, the observed farm products shipments from Iowa to California, the Gulf Coast, and Lower Mississippi Valley regions consist predominantly of unit train and large multiple car movements.

Estimated 2015 Fuel Effects. In the with-project scenarios, the affected traffic would move on the river, thus resulting in reduced fuel consumption, emissions, and a lower occurrence of accidents for the incremental traffic. In general, Alternatives E, F, G, H, and J exhibit the greatest estimated reductions or cost savings because of the greater amounts of affected traffic. As noted earlier, fuel cost reductions are estimated by multiplying an average fuel cost by the estimated reduction in fuel consumption. In 2015, the estimated annual reduction in fuel costs resulting from various waterway improvements ranges between $59 thousand and $4.7 million in 1998 prices, depending on the extent of improvements made. Because fuel expenses are reflected in the cost of each mode, the fuel cost reductions presented in this report are captured already in the transportation cost savings estimated in the UMR-IW National Economic Development (NED) analysis.

Estimated 2015 Emission Effects As noted earlier, emission cost savings are estimated in two alternative ways. The first way is to assume that any incremental pollution resulting from rail transportation in the without-project scenarios will be abated by the railroads. The annual emission cost savings estimated in this way are small, ranging from $3,500 to $278,000 in 1998 prices, depending on the extent of waterway improvements. The second way to estimate the reduction in emissions costs is to assume that any incremental pollution resulting from a shift of waterway traffic to rail in the without-project scenarios will not be abated, and will therefore cause health and property damage. The annual emission cost savings estimated in this way range between $105 thousand and $8.36 million in 1998 prices, depending on the extent of waterway improvements. To the extent that emission costs are internalized by each of the modes, the emissions costs savings may already be reflected in NED benefits. However, if incremental emissions resulting from a shift in traffic from waterway to rail in the without-project scenarios are not abated, then the costs imposed on society will not be reflected in the NED estimates.

Estimated 2015 Accident Effects. Accident cost savings are estimated using accident, injury, and death rates by mode, expected modal traffic shifts, and cost estimates for property damage, injuries, and deaths. This analysis, it should be noted, is not an attempt to place blame. The preponderance of rail-related fatalities and injuries result from highway-rail grade crossing collisions and from trespassers making illegal and ill-advised track crossings. Nevertheless, each injury or fatality entails a social cost. Using 1998 prices, the estimated accident cost savings range from $411,000 to $31.9 million, depending on the extent of waterway improvements. A portion of these costs is probably accounted for in the NED analysis, through the effects of accidents on insurance and casualty costs. However, to the extent that accidents occur where the transportation mode is not liable, the comprehensive costs of accidents are not captured by the NED benefits. Highway grade-crossing accidents may result in lawsuits against state, county or local governments instead of against the railroad. Moreover, there may be many instances in which the railroad is not held liable trespasser accidents. The extent of future railroad liability is uncertain and may be affected by the outcome of pending court cases. Clearly, a more detailed analysis is needed before definitive conclusions can be drawn regarding the portion of accident cost savings that is included in the NED benefit estimates.

Summary of 2030 and 2050 Benefits. In 1998 prices, the estimated total fuel, emission, and accident cost reductions resulting from the proposed improvements range between $507 thousand and $40 million in 2015, between $386 thousand and $47 million in 2030, and between $323 thousand and $64 million in 2050 under the assumption that incremental emissions are not abated. In these scenarios, additional health and property damage costs from air pollutants are imposed upon society. Under the scenarios where emissions are abated, the cost reductions from various alternatives range between $406 thousand and $32 million in 2015, $311 thousand and $37.5 million in 2030, and $262 thousand and $51 million in 2050. These estimates are subject to the same questions and limitations as the 2015 estimates and therefore should not be added to the NED benefits without further study.

POTENTIAL NOISE AND OTHER IMPACTS

A detailed review of transportation noise impacts was also undertaken. Most noise studies address highway, aircraft, or high-speed rail noise. It was not possible within the time frame of the study to estimate railway noise costs, and the literature review did not discover factors that could be used with confidence. Nevertheless, a qualitative background analysis is presented in the report.

Measurement of Noise. As described in the report, loudness is defined by sound pressure level (SPL) which is measured in decibels (dB). Because the decibel is a logarithmic unit, a doubling of source noise results in only a 3 dB increase in the existing sound pressure level. On the logarithmic scale, a 10-dB change in SPL is perceived by humans as a doubling or halving of loudness. The A-scale on a sound-level meter is used most often in noise analysis because it best approximates the frequency response of the human ear. In a 24-hour period, A-weighted decibel (dBA) sound levels may range from 30 (very quiet) to 90 (very loud) or greater. Background or residual sound level is about 45 dBA.

Maximum Train Noise Levels. Although railroad noise levels were not measured in this study, the maximum allowable railroad noise levels were obtained from 40CFR201. Under these regulations, a locomotive manufactured after December 31, 1979 cannot produce sound levels in excess of 90 dBA when in motion, although the maximum noise emission of older locomotives is somewhat higher (96 dBA). Moreover, a rail carrier cannot operate rail cars that produce sound levels (while in motion) in excess of 88 dBA at speeds up to and including 45 mph, or 93 dBA at car speeds greater than 45 mph, when measured at 100 feet from the centerline of the track. It should be noted that these noise regulations do not apply to train horns. Given the regulatory maximums, it is likely that a freight train in motion produces noise levels of 88 to 96 dBA at distances of 100 feet from the track along a line source of several minutes duration. Moreover, it appears that a substantial increase in trains per day through a community has the potential for increasing existing noise levels in relation to community impact thresholds which are in the 55-65 dBA range.

Horn Noise. The locomotive horn or whistle is a very controversial community issue that has implications for both safety and noise levels. The FRA noise impact model is based on an sound equivalent level of 107 dBA at 100 feet from the tracks for locations not closer than one-eighth mile from a grade crossing. Many community complaints arise in regard to nighttime soundings of the horn when ambient noise levels are much lower than during the day. In calculating an equivalent 24-hour noise level (L_{dn}), a 10-dBA correction factor is added to nighttime noises to account for increased annoyance from loss of sleep. A number of communities across the nation have regulated or attempted to regulate the use of locomotive horns in their jurisdictions. Federal Railroad Administration currently is involved in a rule-making proceeding to address the use of locomotive horns at public grade crossings. The elimination of community whistle bans would improve safety but would have a substantial noise impact in the study region. Nearly half of all persons potentially impacted by the elimination of whistle bans reside in the state of Illinois. Wisconsin and Minnesota rank third and fifth respectively in terms of potentially impacted populations.

Noise Cost Estimates. In the 1997 Highway Cost Allocation Study, Federal Highway Administration (FHWA) quantified the impacts of highway noise on residential property values. Using a middle-range estimate from a widely-quoted study, FHWA concluded that a dBA increase in noise above the community impact threshold of 55 dBA would result in a .4 percent decrease in property values. Using the median housing value from the 1993 Census survey, annualized at a 10 percent discount rate and multiplied by the 0.4 percent, FHWA estimated a highway noise cost of about $35 per decibel per housing unit. Although housing residents may not react in exactly the same way to railroad noises, highway noise factors provide some insights as to potential changes in market valuations that might result from increased railroad noise.

STB Environmental Analysis Thresholds. The Surface Transportation Board has established thresholds for evaluating whether potential changes in railroad traffic and operations might result in significant environmental impacts. If a proposed action affects a class I or nonattainment area under the Clean Air Act, and will result in either: (a) an increase in rail traffic of at least 50 percent or an increase of at least three trains a day on any segment of rail line, or (b) an increase in rail yard activity of at least 20 percent, then the railroad's environmental report must state whether any expected increased emissions are within the parameters established by the State Implementation Plan. If a proposed action affecting any area would result in: (a) an increase in rail traffic of at least 100 percent or an increase of at least eight trains a day on any segment of rail line affected by the proposal, or (b) an increase in rail yard activity of at least 100 percent, the railroad's environmental report must quantify the anticipated effect on air emissions and noise. If the proposed action will cause an incremental increase in noise levels of at least three decibels L_{dn} or an increase to a noise level of 65 decibels L_{dn} or greater, the report must identify and quantify the noise increase for sensitive receptors (e.g., schools, libraries, hospitals, residences, retirement communities, and nursing homes) in the project area. The STB thresholds are related to potential rail system changes such as construction, abandonment, and mergers. However, they describe incremental railroad traffic levels that might trigger an environmental analysis during a regulatory proceeding.

CONCLUSION AND RECOMMENDATIONS FOR FURTHER STUDY

Because of the high level of data aggregation and short time frame[2], the results should be viewed as general findings. As noted previously, a separate traffic forecast was not prepared for this study. Therefore, the findings are linked to the traffic forecasts provided by USACE for the "with project" and "without project" scenarios.

As the report suggests, railroads have become much more fuel efficient over time and the relative energy benefits of waterway transportation have become smaller. However, the analysis shows that there is a relatively small fuel advantage to barge transportation in this instance. This fuel efficiency advantage translates into lower emissions for the incremental traffic in the with-project scenario. However, the dollar benefits are not large assuming that railroads internalize the cost — in which case, the emission cost is equivalent to a compliance cost. However, if railroads don't internalize the emission cost, a larger cost to society will result from pollution damage to health, property, and vegetation. Without further analysis and comparison, the proportion or percentage of emission cost reflected in the NED calculations cannot be ascertained.

The study did not address potential impacts on non-attainment areas, where even a relatively modest increase in emissions could have significant impacts. Many of the alternatives would result in at least three incremental trains per day, and depending upon the routes involved, could meet the STB threshold for an environmental impact assessment. Although the STB thresholds would not apply to traffic diverted from waterways to railroads, such a finding would suggest that a detailed analysis of potential impacts is warranted.

In general, more research is needed to firm-up the emission, safety, and noise impacts. The accident approach used in this study could be improved by: (1) estimating a statistical model of railroad accidents instead of using average accident rates; (2) estimating accident probabilities for grade crossings, based on both rail and highway traffic exposure and crossing characteristics; (3) looking at hazmat issues such as risk assessment and the broader implications of a hazmat grade crossing accident; and (4) analyzing the relationship between comprehensive accident cost and railroad casualty and insurance cost. In the report, BNSF's 1998 casualty and insurance costs are compared to estimated comprehensive accidents costs for accidents on that railroad. In this comparison, the estimated comprehensive accident cost is much greater than the reported casualty and insurance cost, suggesting that all aspects of comprehensive accident costs may not be internalized by railroads. This example is for one railroad and year only, but it does indicate that a more detailed multi-year comparison is warranted.

2 The draft report was prepared during January and February of 2000.

As noted earlier, changes in noise levels may result from increased rail traffic. However the impacts will depend on the routes traveled, the population exposed to noise on the routes, and existing noise levels. Many communities in Illinois, Wisconsin, and Minnesota would be impacted heavily by the proposed elimination of train whistle bans. In general, train noise is an important issue in the study region and warrants more study. With more specific traffic and route data, it may be possible to forecast instances when the STB threshold criteria are reached.

Note. *The USACE contracted with Tennessee Valley Authority to review this report. The comments of the reviewers are attached as Appendix D to the main report, along with my responses to their comments.*

1. INTRODUCTION

This report presents an analysis of the energy, emissions, and safety implications of potential investments in the Upper Mississippi River and Illinois Waterway (UMR-IW) System. About 130 million tons of traffic have been identified as moving on the UMR-IW system for at least part of the trip.[1] The U.S. Army Corps of Engineers (USACE) has identified 10 alternative improvements to the UMR-IW System. The alternatives encompass several small-scale and/or large scale improvements such as the construction of lock extensions, the extension of guidewalls, and the construction of mooring cells.

The proposed small-scale improvements consist of: (1) the construction of adjacent mooring cells at Locks 12, 18, 20, 22, and 24 on the Upper Mississippi River and (2) the extension of guidewalls to 1,200 feet (with powered kevels) at Locks 14-18 on the Upper Mississippi River and at the Peoria and LaGrange Locks on the Illinois Waterway. The proposed mooring cells will provide vessels with places to tie off while waiting to transit a lock. Without these facilities, towboats may have to wait farther away from the lock, out in the river's currents, thus consuming additional fuel. The extended guidewalls will reduce lock time by allowing the reassembly of a double-cut tow to take place outside of the lock chamber along the extended guidewalls, thus freeing-up the lock chamber faster. Longer guidewalls will provide for easier maneuvering of tows and may allow for a reduction in approach time.

The proposed large-scale improvements consist of extending Locks 20-25 on the Upper Mississippi River to 1200 feet and constructing new 1200-foot locks at Peoria and LaGrange on the Illinois Waterway. These improvements would obviate the need for disassembly and reassembly of a 15-barge tow and eliminate the additional lock transit presently required.

The various project alternatives are summarized in Table 1. For each alternative, the USACE has developed traffic forecasts with and without the potential improvements for three future years: 2015, 2030, 2050. These forecasts are based on: Waterway Traffic Forecasts for the Upper Mississippi River Basin, by Jack Faucett Associates (April, 1997) and a detailed economic model described in: A Spatial Price Equilibrium-Based Navigation System NED Model For the UMR-IW Navigation System Feasibility Study (USACE, 1998). The USACE report describes the economic theory underlying the model and discusses potential National Economic Development (NED) benefits. Readers are referred to the 1998 report for background information regarding traffic forecasts and assumptions.

Scope of Study

The USACE traffic forecasts and alternate routes are the starting point for this analysis. They are taken as inputs and are not analyzed further. The key information source is a data package provided by the Corps which contains forecasted waterway tons for the "with-project" and "without-project" scenarios, as well as the incremental tons for each alternative — i.e., the difference between the without-project and with-project scenarios. The USACE data file includes traffic forecasts for specific commodity movements among eight states or regions — Illinois, Iowa, Minnesota, Missouri, Wisconsin, Lower Mississippi Valley, Eastern United States, and Western United States — as well as the average waterway distance for each origin-destination combination. The estimated incremental rail tons and incremental rail ton-miles for the without-project future are summarized in Table 2.

Table 1. Description of Project Alternatives

Alternative	Project Description
A	Mooring Cells at Lock Sites: 12, 18, 20, 22, 24
B	Mooring Cells at Lock Sites: 12, 18, 20, 22, 24 and Powered Kevel Guidewalls at Locks 20-25
C	Extend Locks 20-25 to 1200 Feet
D	Extend Locks 20-25 to 1200 Feet and Powered Kevel Guidewalls at Locks 14-18
E	Mooring Cells at Lock Sites: 12, 18, 20, 22, 24 and Extend Locks 20-25 to 1200 Feet and Powered Kevel Guidewalls at Locks 14-18
F	Mooring Cells at Lock Sites: 12, 18, 20, 22, 24 and Extend Locks 20-25 to 1200 Feet and Powered Kevel Guidewalls at Locks 14-18 and Peoria & LaGrange
G	Extend Locks 20-25 and 14-18 to 1200 Feet
H	Extend Locks 20-25 to 1200 Feet and New 1200-Foot Locks at Peoria & LaGrange and Powered Kevel Guidewalls at Locks 14-18
I	Mooring Cells at Lock Sites: 12, 18, 20, 22, 24 and Powered Kevel Guidewalls at Locks 14-18 and 20-25
J	Mooring Cells at Lock Sites: 12, 18, 20, 22, 24 and Extend Locks 20-25 to 1200 Feet and New 1200-Foot Locks at Peoria & LaGrange and Powered Kevel Guidewalls at Locks 14-18

The scope of this study is defined partly by three key traffic-related assumptions. First, rail transportation is assumed to be the only feasible alternative to barge movements. This is a tenable assumption given the commodities and distances involved. Second, the rail distance is the same as the waterway distance for commodities other than grain. Most of the contested river traffic consists of grain shipments. Thus, the second assumption is not a critical one. Third, any gathering or distribution movements by truck at origin or destination are not reflected in the analysis. The implied assumption is that truck traffic patterns do not change appreciably from the without-project to the with-project scenario. These three simplifying assumptions were necessary in order to conduct the study within the desired time frame. To the extent that truck gathering and distribution patterns vary across alternative futures, some energy, air quality, and safety effects may not be accounted for in the analysis.

Table 2. Incremental Tons and Rail Ton-Miles in the Without-Project Future

Alternative	2015		2030		2050	
	Incremental Tons (Thou.)	Inc. Rail Ton-Miles (Million)	Incremental Tons (Thou.)	Inc. Rail Ton-Miles (Million)	Incremental Tons (Thou.)	Inc. Rail Ton-Miles (Million)
A	176	257	134	199	111	169
B	4,807	6,729	5,724	8,018	6,596	9,219
C	7,551	10,514	9,048	12,614	11,141	15,468
D	10,730	15,040	13,351	18,746	15,752	22,099
E	11,035	15,471	13,756	19,317	16,458	23,101
F	11,480	16,039	15,076	21,014	20,996	29,035
G	14,285	19,990	16,827	23,706	17,294	24,318
H	11,812	16,415	15,756	21,844	22,983	31,599
I	5,705	8,018	6,453	9,096	7,069	9,944
J	12,095	16,816	16,193	22,463	23,717	32,644

An important question is whether the impacts quantified in this study represent additions to benefits counted previously in earlier phases of the NED analysis. In this study, diesel fuel is valued at its market price — meaning that non-market costs (such as energy security) are not considered. Thus, any change in energy cost estimated in this report is not additive to the NED benefits computed previously. Nevertheless, the energy analysis is important because it provides for an explicit comparison of modal energy efficiencies and is a necessary prerequisite to the emissions study.

The answer to the above question is not so clear for pollution and safety impacts. The earlier NED analysis used costs as a surrogate for transportation rates. Since insurance costs are an explicit component of barge and rail costs, insured losses are accounted for in the National Economic Development evaluation. However, it is not readily apparent that all safety and pollution costs are internalized or borne by the railroad. For example, highway grade-crossing accidents may result in lawsuits against state, county or local governments instead of against the railroad. These complicated questions are taken up later in the report, when potential emissions and safety benefits are quantified. The report now turns to a preliminary discussion of methods and data sources.

Overview of Analytical Methods and Data

At the outset, a criterion should be stated for comparing the energy efficiency of railroads and barges. Typically, energy comparisons are made on the basis of revenue ton-miles per gallon (RTMG). This factor relates output (revenue ton-miles) to the consumption of an input: fuel. It is a single-factor productivity measure. Although other criteria could be used, RTMG is a widely-accepted measure for evaluating the energy impacts of potential shifts in traffic among modes and will be used as the comparative standard in this study.

Approach to Energy Efficiency Analysis. It is expected that both barge and railroad fuel efficiencies will increase during the analysis period. Thus, RTMG factors should be higher for both modes in 2015 than the current or recently-observed values. However, predicting how relative fuel efficiencies will change is a very difficult task. Class I railroads already have made tremendous strides in fuel efficiency during the last two decades as a result of: computerized locomotives and other improvements in locomotive technology, longer trains and high-capacity freight cars, better utilization of track capacity through advanced traffic control and signalization systems, and reductions in branch-line operations and switching activities. These efficiency gains are reflected in the data used in this study. Clearly, railroads may further improve fuel economy through continued progression of the technologies noted above, as well as through the widespread deployment of emerging technologies such as AC-powered locomotives. However, it is reasonable to expect that marine diesel engine manufacturers will strive for further fuel efficiency gains in the future, particularly given the recent trend in fuel prices. For these and many other reasons, it is virtually impossible to forecast RTMG factors for rail and barge in 2105 and beyond. The major concern of this study is with the difference in fuel efficiency among modes. Therefore, it is assumed that the relationship between rail and barge fuel efficiencies is the same in 2015 as that which is possible today.

Railroad Energy Efficiency. Several alternatives exist for estimating railroad energy consumption. Aggregate industry indicators (such as revenue ton-miles per gallon) are sometimes are used for broad comparisons. However, the use of an aggregate fuel consumption factor would obscure considerable variation within the railroad industry and would not account for differences in movement types, train characteristics, and geography. In some instances, computer simulators pose a useful alternative to industry averages. Train simulators produce very detailed theoretical results for specific routes and operating conditions. The results of recent simulations are discussed and utilized in this study. However, the project scenarios encompass many commodities, markets, and possible routings. The forecasts are based on likely distributions of markets for grain and other commodity movements well into the future. Such forecasts involve some degree of uncertainty; markets could shift or carriers and routes could change. For such a broad future analysis, reliance upon a limited set of computer simulations would increase the level of uncertainty. Moreover, as a practical matter, the time frame of the study would not have allowed the development of the detailed route data needed for computer simulations. Instead, an empirical approach is adopted in which statistical models of railroad fuel consumption are estimated from Class I railroad data. Simulations generated from these models are compared to estimates derived from train performance simulators and other sources identified in the literature review.

Barge Energy Efficiency. The development of waterway fuel models is beyond the scope of this study. Instead, published barge fuel consumption factors are used. Barge energy factors have been obtained from two sources: the Tennessee Valley Authority (TVA) and the Corps. A 1999 USACE report uses theoretically-efficient estimates of 450-700 revenue ton-miles per gallon for 15-barge grain tows on the Upper Mississippi River and Illinois Waterway system.[2] The same study uses 700-1000 RTMG as an efficient range for 30-barge tows on the Lower Mississippi River. In comparison, data provided by TVA for 1995, 1996, and 1997 indicate that revenue ton-miles per gallon ranged from 306 to 320 on the Upper Mississippi River and from 259 to 312 on the Illinois River (Table 3). According to TVA estimates, revenue ton-miles per gallon during the same period ranged from 604 to 646 on the lower river segment from Cairo, Illinois to Baton Rogue, Louisiana. These values, it should be noted, are applicable to all river traffic, not just the contested movements. In the with-project scenario, upper river fuel efficiencies are expected to be higher than historic values because of the effects of the proposed lock and guidewall extensions and mooring cells. Considering the efficient and historical estimates and a range of movement distances, a value of 375 RTMG was selected for the upper river system. A value of 644 RTMG was used for the lower river system. This latter value corresponds to the middle year (1996) of the TVA data. To the extent that the efficient barge estimates developed by USACE are realized in the future, the RTMG values used in this study may understate river fuel efficiency.

Table 3. Estimated Revenue Ton-Miles per Gallon for Mississippi River Segments

River Segment	Revenue Ton-Miles per Gallon		
	1995	1996	1997
Minneapolis-to-Mouth of Missouri River	308	306	320
Illinois River	312	283	259
Mouth of Missouri River-to-Mouth of Ohio River	595	560	520
Mouth of Ohio River-to-Baton Rouge	646	644	604

Source: Tennessee Valley Authority

Emissions Analysis. In the 1990 Clean Air Act Amendments, both rail and barge transportation were brought under the regulatory authority of the Environmental Protection Agency (EPA). In the future, EPA standards are expected to uniformly limit emissions per gallon of fuel for non-road freight sources. The approach used in this study is to multiply the estimated difference in gallons of fuel consumed by emission rates per gallon. As discussed later, there are several potential ways to value incremental emissions. One approach is to multiply the increase in emissions by a unit cost of pollution abatement (which can be computed from EPA data). The result is an estimate of the direct costs associated with changes in emissions. However, the social cost of pollution may be higher than abatement costs under certain circumstances. If incremental emissions are not abated by further improvements in emission control technology, or offset by reductions elsewhere, direct cost estimates will understate the cost of pollution to society. Estimating the social costs of incremental emissions is a complex undertaking. However, air quality cost factors used by Federal Highway Administration (FHWA) provide a simplified means of assessing air pollution costs. The theory and techniques of each approach are detailed later in the report.

Safety Data. The quantification of accident costs is a multi-step process in which annual accident-related costs are estimated for the with-project and without-project scenarios. Without-project accident costs are based on railroad accident factors, while with-project costs reflect waterway accident data. Three categories of costs are analyzed for each mode: property damage, injuries, and fatalities. A two-step analysis process is followed for both rail and barge transportation: (1) estimate the annual accidents, fatalities and injuries for the incremental traffic and (2) multiply the annual events by the applicable unit cost per property damage, fatality or injury. The railroad accident data used in this study are derived from Federal Railroad Administration (FRA) reports and bulletins. Waterway accident rates and costs are derived from a previous study conducted for the USACE by University of Memphis.

The purpose of this introductory section has been to highlight the project alternatives and study approach. In subsequent parts of the report, incremental energy, emissions, and safety impacts are quantified for each alternative. In each section, the data sources and analytical methods are covered in depth. The main text of the report begins with a detailed analysis of railroad energy efficiency and fuel consumption factors.

2. RAILROAD FUEL CONSUMPTION DATA AND MODELS

Analyzing and predicting railroad fuel consumption is an important step in the analysis of waterway investments and alternatives. As noted earlier, railroad is the alternate mode for grains and other bulk commodities moving on the Upper Mississippi River and Illinois Waterway System. Railroad fuel consumption is important to energy conservation goals, and is important from an environmental and analytical perspective. Many engine emissions are related directly to fuel consumption. Future U.S. emission standards are expected to prescribe limits for all modes in terms of emissions per gallon of fuel consumed. In essence, the modal energy comparison sets the stage for the rest of the report.

Part 1 of this section presents a review of previous studies and alternative approaches. In Part 2, Class I railroad data are used to describe fuel efficiency trends and to estimate statistical models of railroad fuel consumption. In Part 3, the results of the statistical analysis are used with estimates from the literature to define a range of probable railroad fuel consumption factors applicable to contested river traffic.

Six major approaches to the analysis of railroad fuel consumption have been documented in the literature: (1) industry averages, (2) resistance equations, (3) propulsive work equations, (4) computer simulators (train performance simulators or calculators), (5) shipment costing models, and (6) statistical models. Propulsive work equations are theoretical in nature and are not discussed in this report. The purpose of this section is to describe the data requirements and potential applications of the analytical approaches and indicate which ones are appropriate for this study.

Industry Averages

The American Association of Railroads (AAR) annually publishes revenue ton-miles per gallon for the Class I railroad industry. As Table 4 shows, railroads have become much more fuel efficient over time. The gross quantity of fuel consumed is only slightly greater in 1998 than in 1960, in spite of the fact that revenue ton-miles have more than doubled during the period. Much of the reason lies with locomotive advances such as automated throttle controls and improved engine performance. The widespread adoption of microprocessor control systems has greatly improved locomotive traction performance and reliability.

Although locomotive technology has improved greatly during the last three decades, the fuel efficiency trend reflects network changes and other operational factors. Mergers, line sales, and abandonments have further concentrated traffic in mainline corridors. Class I carriers now perform less consolidation and local delivery service and more through and unit train movements.

Table 4. Revenue Ton-Miles Per Gallon of Railroad Fuel

Year	Revenue Ton-Miles (millions)	Fuel Used in Freight Service (million gallons)	Revenue Ton-Miles per Gallon
1960	572,309	3,463	165
1970	764,809	3,181	240
1980	918,958	3,904	235
1990	1,033,969	3,115	332
1998	1,376,802	3,583	384

Source: Railroad Facts: 1999 Edition, American Association of Railroads (AAR)

Although the railroad industry average is insightful, it is not very useful for analytical purposes. Fuel consumption patterns may vary widely among railroads as a result of traffic patterns, climate, terrain and other factors. The AAR value is computed from detailed data provided by individual railroads in their annual reports to the Surface Transportation Board (STB). As will be shown later, it is possible to compute firm averages and specific trends for individual Class I railroads — which in some cases are quite different from the industry mean.

Factors Affecting Train Resistance

Many resistance equations have been developed from railroad engineering formulas and field studies. Although the equations require detailed data to apply, many of the concepts are relevant to this comparison and are discussed briefly.

Train resistance usually is measured in pounds per ton of train weight and is a function of many factors including (but not limited to): (1) rolling resistance, (2) flange resistance, (3) journal (axle) resistance, (4) track resistance, (5) air resistance, (6) curve resistance, and (7) grade resistance. Journal, rolling, and track resistance are related to axle loads. The journal is the part of the axle that rotates in or against a bearing. The original design was a "plain bearing axle" in which the journal rotated within a bronze bearing, constantly lubricated by adjacent oil-soaked fibers. Starting in the 1960s, plain bearing axles were gradually replaced with reduced-friction roller bearing axles. Rolling train resistance results mostly from the friction of car wheels in contact with the tops of rails. This type of resistance is different from flange resistance which results from contact between the wheel's flange and the inside head of the rail. Track resistance results from bending or deflection under a moving train load. The rail directly under a wheel load is depressed. However, a reverse upward bending of the track occurs in front of and behind the wheel. In effect, a car wheel is "running uphill" against a reactive wave of deflection. Heavier rail reduces bending and track deflection but does not eliminate track resistance.

Air resistance varies approximately with the cross-sectional frontal area of the vehicle and the square of speed (Hay, 1982). It is affected also by equipment profiles and the potential for localized air disturbances in vehicle frontal areas and under frames. Trailer-on-flatcar (TOFC) shipments and automobile carriers or "autoracks" are thought to be especially problematic.[3] Pockets of air may be encapsulated within the framework of an empty uncovered rack car. The sloping fronts of trailers and the varied configurations of trailers and containers on flatcars can create localized air turbulence. Covered tri-level auto carriers and double-stack container cars are problematic because of their heights.

The composition of a train and the placement of cars within a train can improve or worsen air resistance. Theoretically, solid trains of like cars should reduce air resistance per ton in comparison to mixed freight trains. Moreover, groupings of cars of like contours within a train should minimize air resistance. Trainmasters try to avoid repeated high-car, low-car combinations and repeated single trailers or containers on long flatcars (Rhine, 1997).

Curve and grade severity are important factors in train resistance equations. Curve resistance represents the additional work needed to overcome wheel-rail friction beyond that which results from movement over straight or tangent track. Flange lubricators located on locomotives or trackside can greatly reduce curve resistance. However, grade resistance is a function of terrain and route location. Generally speaking, unit grade resistance is about 20 lb/ton per percent of grade (Hay, 1982). The total resistance to be overcome by a locomotive consists of all other resistance plus grade resistance.

Resistance Equations

Davis (1926) and the American Railway Engineering Association (1970) derived comprehensive train resistance equations and adjustment factors that incorporate most of the effects described above. These resistance equations, which are detailed in Hay (1982), have been incorporated into many train performance simulators and analytical models.

A series of resistance studies were conducted in the 1970s that provide simplified estimation techniques and generalized results. Some of the results were used by Federal Railroad Administration and state transportation departments during a period of intensified rail planning and community impact analysis. In a 1974 study, Peat, Marwick and Mitchell and Jack Faucett Associates related railroad and truck fuel consumption to resistance in pounds per net ton. The study focused on rail box car, TOFC, and truck movements. The factors shown in Table 5, which resulted from the study, were adopted by FRA for generalized use in federal and state rail planning. Although insightful, the fuel consumption factors reflect railroad equipment, load factors, train characteristics, signalization systems and other technologies of the 1970s and thus are outdated.

Table 5. Fuel Consumption Factors Used in State Rail Planning, 1978

Type of Train Service	Gallons of Diesel Fuel per 1,000 Net Ton Miles	Revenue Ton Miles per Gallon
Short-Haul Rail	24.90	40
Through Train	5.05	198
Unit Train	2.38	420
TOFC	5.77	173

Source: Rail Planning Manual, Volume II, Federal Railroad Administration, 1978

Although outdated, the factors in Table 5 illustrate that railroad fuel consumption is greatest for branch-line or way train operations. Way trains decelerate frequently to stop at way stations where they spot empty cars and pull loaded ones. After switching, a way train accelerates to a relatively slow cruising speed (such as 25 mph) only to decelerate shortly thereafter and stop at the next station. This cycle of acceleration and deceleration consumes excess fuel for a given train load and distance. Train switching activities at way

stations further contribute to poor fuel economy.
An analytical approach for estimating fuel consumption for branch-line operations was developed for the Pennsylvania Department of Transportation by R.L. Banks & Associates (1975). The approach, later adopted by FRA, consisted of a three step process: (1) calculate the tractive effort required to move a train over a branch-line segment, (2) convert tractive effort into horsepower-hours, and (3) use an average rate of fuel consumption (0.06 gallons per horsepower-hour) to estimate energy use for the segment. Tractive effort describes the work that must be expended by the locomotives to pull the train. A change in tractive effort occurs when a train accelerates, decelerates, or encounters a change in grade or curvature. The general formula is shown in equation (1).

$$(1) \quad TE = \pm 70(V_i^2 - V_f^2) + (R + 20G + 0.8D)$$

where:

V_i = Initial train speed (mph)
V_f = Final train speed (mph)
R= Train resistance in pounds per ton for a specified speed
G= Grade (in percent)
D= Degree of curvature

Equation (1) actually consists of two additive terms. The term $70(V_i^2 - V_f^2)$ describes the tractive effort required to accelerate or decelerate a train, while the term $R + 20G + 0.8D$ describes the energy required to overcome the rolling resistance of the train. When a train is neither accelerating nor decelerating, the first term equals zero and tractive effort is equal to train resistance.

Applications of equation (1) require detailed information about grades, curves, and speed limits. The equation works best for relatively short track segments. Most of the contested traffic in this study would move long distances via railroad mainlines under the “without” scenario. Thus, the detailed approach shown in equation (1) is primarily relevant to gathering movements, which comprise a small percentage of total train miles.

Train Performance Simulators

A train performance simulator (TPS) is a computer program that simulates the performance of a train over different sections of track. The results can be synthesized to yield performance values for an entire route. A TPS uses grade, curvature, speed limits, signalization, and train consist data to simulate time, cost, and fuel consumption. Train resistance equations —resident within a TPS— are used to calculate fuel consumption for different combinations of train loads and equipment. During the 1970s, the Southern Railway, the Missouri Pacific, and the St. Louis and San Francisco Railway, among others, developed train performance simulators. Many Class I railroads continue to use proprietary models for internal management purposes. However, only a limited number of train simulations have been performed within the public domain.

Perhaps the most comprehensive public domain analysis occurred in 1991, sponsored by the Federal Railroad Administration. The consultant—Abacus Technology Corporation— used a TPS originally developed by the Missouri Pacific Railroad, which was later adapted for use by FRA in the 1970s. Three Class I railroads executed the TPS and provided results to Abacus Technology. Altogether, 43 hypothetical rail movements were analyzed, including 32 Class I scenarios and 11 regional and local railroad scenarios. The stated intent of the study was to compare rail and truck energy consumption for truck-competitive rail movements. Railroad and waterway comparisons were not considered. Because of the orientation of the study, most of the railroad simulations featured mixed freight, TOFC, and automobile traffic. The Class I mixed freight simulations encompassed: canned fruits and vegetables and other food products; sawmill, lumber, and paper products; chemical, plastic, and steel products; and motor vehicles and intermodal freight. The primary car types analyzed were: box cars, general service flatcars, standard TOFC flatcars, and covered hopper cars. In addition to the 13 Class I carrier mixed trains, 11 regional or local railroad train movements were analyzed. Corn and other grains, pulpwood and wood chips, and steel and chemical products were included in the regional/local simulations. Although standard TOFC movements were included in the mixed freight scenarios, 16 separate TOFC simulations were performed. Eleven of them related to standard TOFC/COFC trains. The other five simulations specifically addressed the fuel efficiency of double-stack intermodal trains. In addition, one solid auto train was analyzed.

Table 6 summarizes the train type and trailing weight of the 32 Class I scenarios. The average trailing weight is the average gross tons being pulled by the locomotives; i.e., the average train weight. As Table 6 shows, the trailing weight of mixed freight trains in the Class I simulations varies from about 1,900 to 10,300 tons, with a mean of 6,484 tons. It is important to note that the average trailing tons is a mixture of loaded and empty cars, as is typically the case in a mixed freight train. As Table 6 shows, the average trailing weight of the hypothetical TOFC trains is about half that of the mixed freight trains. Double-stack and solid auto trains are heavier than TOFC trains, but lighter than mixed freight trains.

The results of the simulations are very insightful. The estimated fuel efficiencies range from 414 to 843 RTMG for mixed freight trains, and from 279 to 499 RTMG for mixed freight trains with autoracks (Table 7). In comparison, the estimated fuel efficiencies range from 196 to 350 RTMG for TOFC trains. Perhaps the most surprising results are for local and regional railroads. As Table 8 shows, the estimated fuel efficiencies are very high for small way train movements and appear to contradict the relationships shown earlier in Table 5. However, caution should be exercised in drawing inferences from the FRA simulations. Their stated purpose was to compare the fuel economy of railroads and trucks for a limited set of commodities. The basis for comparison was the train movement, not the shipment. With one exception, the hypothetical trains in the regional and local simulations consist of loaded cars only. The fuel required for delivering empty cars to shippers and for terminal switching operations is not accounted for in the analysis. Moreover, the train simulations do not reflect the consolidation of cars at multiple stations, as is typically the case in way train operations. Consideration of speed change cycles and station switching activities would greatly reduce the RTMG estimates for regional and local railroads. Similarly, 13 of the 32 Class I scenarios consisted of all loaded cars. Only 6 percent of the cars in the 32 Class I simulations were empties.

Table 6. Trailing Weight Characteristics of Class I Scenarios in FRA Study

Train Type	Average Trailing Tons	Range in Trailing Weight	Class I Scenarios
Mixed Freight	6,484	1,909 - 10,320	13
Mixed Freight with Autos	5,938	5,475 - 6,400	2
Double-stack	5,695	4,421 - 6,908	5
TOFC	3,410	1,980 - 4,536	11
Solid Autos	4,580	4,580	1
All Class I Scenarios	5,245	1,909 - 10,320	32

Source: Federal Railroad Administration, *Rail Vs. Truck Fuel Efficiency*, 1991

Table 7. Revenue Ton-Miles per Gallon for Class I Scenarios in FRA Study

Train Type	Range in RTMG Estimates	
	Minimum Value	Maximum Value
Mixed Freight	414	843
Mixed Freight with Autos	279	499
Double-stack	243	350
TOFC	196	327
Solid Autos	206	206

Source: Federal Railroad Administration, *Rail Vs. Truck Fuel Efficiency*, 1991

Table 8. Simulated Fuel Efficiencies of Regional and Local Railroads from FRA Study				
Scenarios	**Cars per Train**	**Loaded Cars**	**Trailing Tons**	**RTMG Range**
4	90	70	5,650	596 - 668
3	60	60	4,380	625 - 682
2	10	10	730	890 – 1,104
2	25	25	1,825	1,086 – 1,179
Source: Federal Railroad Administration, *Rail Vs. Truck Fuel Efficiency*, 1991				

The FRA simulations were appropriate for comparison with trucks, which typically experience 15 percent empty miles or less for van and flatbed trailer movements. However, the results are not very relevant for railroad-waterway comparisons. Typically, rail grain shipments in covered hopper cars incur 45% to 50% empty miles. For unit grain trains, the implied empty-to-loaded ratio is 1.0. In spite of these caveats, the FRA simulations are important in terms of setting expectations for the statistical analysis to follow, and in isolating the effects of TOFC and auto trains on rail fuel efficiency.

A 1999 study by Gervais and Baumel used computer simulations provided by two Class I railroads for unit grain train movements from Boone, Iowa to New Orleans and Los Angeles. The hypothetical movements consisted of 100-car trains for two different car load factors: 100 and 110 tons. The 110-ton load factor corresponds to a 286,000-pound covered hopper car which has become commonplace in the transportation of grain. A 110-car movement from Sioux City to Tacoma, Washington also was evaluated. Each trip was simulated with three different types of locomotives. The high-end fuel efficiencies shown in Table 9 reflect the use of new high horsepower SD60 and C40-8 locomotives, while the low-end estimates reflect the use of SD40 locomotives commonly used to pull unit grain trains. The Gervais-Baumel values reflect the empty return of covered hopper cars. They will be used later in establishing fuel efficiency bounds for rail grain shipments.

Table 9. Simulated Fuel Efficiency of Unit Grain Trains Movements from Iowa				
Origins-Destinations	**Simulations**	**Cars per Train**	**Load per Car**	**RTMG Range**
Boone, IA to Los Angeles	6	100	100, 110	513-585
Boone, IA to New Orleans	6	100	100, 110	688-802
Sioux City to Tacoma	2	110	110	554-664
Source: Gervais and Baumel. *Fuel Consumptions for Shipping Grain Varies by Origin, Destination*. Feedstuffs, Vol. 71(36).				

This section of the report concludes with a discussion of other train performance simulators and a summary of issues associated with their use. The Transportation Technology Center (TCC) at Pueblo, Colorado has developed several proprietary vehicle simulation models. The Train Energy Model (TEM) is a simulation program that predicts energy consumption for specific train consists, routes, and speed profiles. It also can be used for scheduling, train operation, and economic analysis. It includes some artificial intelligence and expert system routines. The TEM describes each train operation in terms of: time in route; fuel consumed, and equipment used (train consist).

In summary, many train performance simulators exist. They provide detailed analytical capabilities and very useful information. However, most of them are proprietary products used for internal railroad decision-making. Train performance simulators provide considerable detail about specific routes. However, a TPS application requires very detailed information – in effect, a complete route profile of track geometry and speed limits. For these reasons, the use of a TPS is beyond the capability of most organizations except railroads, who internally maintain track profile data. Even when consultants and third parties use a TPS, they are dependent upon railroads for data and simulations. Finally, a limited number of simulations may not capture the range of variables and parameters that affect fuel consumption such as climatic variations and train and yard switching frequencies. Nevertheless, they provide valuable information which can be used in a landscape approach. In particular, the Gervais-Baumel estimates will be utilized later in this study.

Shipment Costing Models

Shipment costing models such as the Uniform Railroad Costing System (URCS) estimate fuel consumption for specific types of railroad services: individual car, multi-car and unit train movements. Fuel costs are included in the shipment cost estimates. Thus, it is possible to isolate the fuel cost component, apply a unit cost per gallon, and "back-calculate" the gallons of fuel consumed. This approach was used by Dr. Mark Burton of Marshall University and is reflected in earlier work on this project.[4]

This is an innovative and insightful approach. The URCS includes estimates of switching time at industry locations and switch yards, as well as road train locomotive miles – which are the basis for allocating running fuel costs. Thus, URCS accounts for fuel consumption which might be excluded from TPS analyses. However, the regression coefficients used to estimate cost variability in URCS reflect 1978-1985 data. Many mergers have occurred since then, and many changes have occurred in the locomotive fleet, traffic control, and other aspects of railroad operations. In addition, the underlying URCS fuel cost regression relates road train fuel consumption to locomotive unit miles. In order to accurately forecast fuel consumption, one needs a rather precise estimate of the locomotive power used on a train consist. If the trailing weight of a train approximately matches the system average unit, through, or way train consist the estimated train fuel requirements will approximate the underlying relationship. However, Phase III of URCS uses a linear extrapolation of motive power costs when the actual train weight is different from the railroad average.

The discussion of shipment costing models provides a segue into the discussion of statistical models — the last approach discussed. A wealth of Class I railroad data exists that provides a complementary approach to the TPS and shipment costing approaches. For this study, a database was compiled of Class I data for the period 1989-1998. The database includes gallons of fuel consumed in freight service and many railroad activity measures. Using this database, it is possible to estimate statistical models that either confirm or call-into-question the estimates discussed earlier.

An Empirical Approach

Class I railroads maintain separate accounts for recording locomotive fuel consumed during the year and report these values to the Surface Transportation Board (STB) in Schedule 750 of the R-1 Report. In addition to fuel consumption, Class I railroads report numerous operating and expense data in the same report. Of particular relevance to this study is Schedule 755 **B** *Railroad Operating Statistics* **B** which contains many railroad activity measures. Most of the data used in this study have been acquired from STB in electronic format. However, paper reports have been encoded when necessary. Because the R-1 reports are used by STB for regulatory purposes, they should be valid. Nevertheless, the data have been subjected to statistical checks and cross references when possible.[5]

The data set for the study consists of Class I railroad observations for the years 1989 through 1998. It includes observations for the following railroads: Atchison, Topeka, Sante Fe (ATSF), (Burlington Northern (BN), Chicago & Northwestern (CNW), Conrail (CR), CSX, Grand Trunk Western (GTW), Illinois Central Gulf (ICG), Kansas City Southern (KCS), Soo Line (SOO), Southern Pacific (SP), and Union Pacific (UP). Because of mergers, the number of observations and railroads vary through time. In the database, the names BN and UP are used throughout the period to establish consistent identities over time.

The Soo Line, GTW, ICG, and KCS did not merge during the period. These midcontinent carriers are essentially north-south railroads that operate primarily over level and rolling terrain. They interchange much of their traffic with other Class I carriers. In contrast, UP and BNSF are trans-mountain carriers that frequently traverse the Rocky Mountains when moving products to and from the Pacific Coast. Much of their traffic is local or single-line in nature. The three eastern railroads are distinct from the midcontinent and western carriers in terms of climate, terrain, and other network factors. All three carriers operate in and through the Appalachian Mountains as well as on the Atlantic or Gulf coastal plains. As illustrated later, the inclusion of indicator variables in a regression model can capture many of these network differences.

As shown earlier (Table 4), Class I railroads averaged 384 revenue ton-miles per gallon in 1998. As Table 10 shows, there was considerable variation about the industry mean. The ICG, Soo Line, and BNSF experienced the highest RTMG in 1998. As noted above, ICG and Soo Line are flatland carriers. Over 40% of their ton-miles occur in unit train service. As the data suggest, Soo Line is a relatively uncongested carrier with efficient train operations. Another fuel-efficient carrier —BNSF— is a large railroad reflecting a mixture of plains, mountain, and coastal operations with a high percentage of unit train ton-miles. UP, which operates much of its trackage in the Rocky Mountains and Southwest, is somewhat less fuel-efficient than BNSF. Of the three trans-Appalachian (Eastern) carriers, CSX is slightly more fuel efficient than the others. Although CSX crosses the mountains, the carrier operates considerable trackage in the seaboard coastal plains and has the highest unit train percentage among the eastern carriers.

Two of the smaller railroads exhibit the lowest fuel economy. The Grand Trunk Western operates less than 1,000 miles of road and hauls large amounts of automotive traffic in specialized equipment with high empty return ratios. Very little of Grand Trunk Western's traffic moves in unit trains. Given its traffic mix and network, GTW is not expected to exhibit high fuel economy. Kansas City Southern also operates a relatively small system and experiences relatively short hauls, mostly in way and through trains.

Generally, the data in Table 10 suggest that terrain and geography may influence fuel economy. However, other factors are important such as railroad size, average length of haul, and percentage of unit train traffic. An analysis of the data set shows that considerable variation exists in fuel efficiency across railroads and time. During the 1989-1998 period, RTMG ranged from 181 to 450 within the Class I industry.

Table 10. Fuel Consumption and Key Network Characteristics of Class I Railroads, 1998

Railroad	Miles of Road	Million Rev. Ton Miles per Mile	Percent Unit Train Ton-Miles	Average Distance	Rev. Ton-Miles per Gallon
BNSF	33,353	14.06	44.0	970	406
CR	10,797	9.40	7.0	446	358
CSX	18,181	9.12	37.7	402	378
GTW	646	14.69	9.5	260	317
ICG	2,593	9.01	41.9	321	441
KCS	2,756	7.85	28.5	323	341
NS	14,423	9.25	13.5	367	368
SOO	3,358	6.08	43.5	336	438
UP	33,706	12.82	29.6	792	376

Source: Computed from Class I Railroad Annual Reports to the Surface Transportation Board

Statistical Background

A widely-used statistical technique — least-squares regression — is used to model railroad fuel consumption in this study. This technique mathematically fits a line through observed data points so as to minimize the sum of the squared deviations about the line. Statistical programs such as SAS automatically estimate model coefficients and provided detailed data useful in evaluating the fit of a regression line and the significance of explanatory variables. Before presenting the models and statistical results, an overview is provided of the statistical tests and terminology used in the report.

Usually, the parameters of a regression model are estimated from sample data. In this case, the 1989-1998 data set is viewed as a sample all possible of Class I railroads. At one time, there were more than 100 Class I carriers in the United States. In any given year, a railroad must meet a revenue threshold in order to qualify as a Class I carrier. Viewing the data set as a sample allows the use of probability theory in the analysis of explanatory variables.

If there isn't a linear relationship between a response variable and an explanatory variable, the slope of a regression line should not be significantly different from zero. A t-statistic is used to test for this condition; it is computed as the parameter estimate divided by its standard error. If the standard error is large in relation to the parameter estimate, the t-value will be low. Because the t-statistic has a known probability distribution, it can be used to determine whether there is sufficient evidence to reject the null hypothesis – that the coefficient is not significantly differ from zero.

Most statistical programs print a *p-value* associated with the *t*-value. The *p*-value defines the probability of obtaining a greater absolute value of *t* when the null hypothesis is true. In general, the smaller the p-value, the greater the level of evidence against the null hypothesis (the coefficient is not significantly differ from zero). For example, a p-value of 0.002 means that the probability of obtaining a greater value of *t* is only 2 in 1,000 when the null hypothesis is true. Given this extremely low probability, it is unlikely that the null hypothesis is true. In hypothesis-testing, one may select levels of statistical significance in advance to compare the p-value against. Three significance levels are frequently used in hypothesis testing: 10%, 5%, and 1%. These three levels are referred to commonly as "moderately significant", "significant" and "highly significant", respectively.[6] In this study, a 5% level of significance is used for hypothesis tests.

Statistically, mergers are handled through the use of indicator variables. Each railroad in the data base is represented by an indicator variable. Additional variables are defined to capture merger effects. The variable BNSF assumes a value of 1 for 1996 and each year thereafter, and zero for years prior to 1996. The UP system includes three railroads that appear in the database: UP, SP, and CNW. UP gained control of CNW in 1995 and merged with SP in 1997. Additional merger variables have been defined to control for these events. The variable UPCNW assumes a value of 1 in 1995, and each year thereafter, but is zero otherwise. Similarly, UPSP assumes a value of 1 in 1996, and each year thereafter, but is zero for earlier years.

3. A STATISTICAL MODEL OF RAILROAD FUEL CONSUMPTION

The first of two statistical models is described in this section of the report. The model relates gallons of fuel consumed to activity and network variables. Locomotive fuel use is expected to vary directly with traffic. Thus, a linear model of fuel consumption would not have a logical intercept term, as might be the case for a short-run cost model. If there is no traffic during the year, there should be no meaningful consumption of locomotive fuel. Nevertheless, an intercept term may be included in a fuel model for estimation purposes and to capture unexplained effects.

Activity and Network Variables

In formulating a regression model, measurable traffic variables must be defined. The R-1 report provides two prime candidates: ton-miles and locomotive-miles. Ton-miles account simultaneously for the effects of weight and distance. Gross ton-miles of cars and contents (GTMC) is an example of a ton-mile variable. It reflects the trailing weights of trains and the train-miles or distances traveled. Moreover, GTMC is a proxy for railroad output. It encompasses revenue ton-miles as well as the loaded and empty tare ton-miles of freight cars. The alternative activity measure—locomotive-miles—is strongly correlated with fuel consumption. However, the number and type of locomotive units are determined primarily by the trailing tons in the train. Locomotive units are matched to train weights in light of ruling grades and other operational factors. Locomotive-miles are a function of GTMC, but the reverse is not true. Although locomotive-miles are a measure of train activity, they are not a measure of output. Therefore, GTMC is the best activity variable for a fuel consumption model.

Railroads collect and report GTMC for three classes of train service: way, through, and unit. Each train class is unique in terms of its operational characteristics and size. Train size is important to fuel economy because locomotive capacity is more fully utilized by longer trains, even though the trailing tons are greater. Locomotives are not added continuously, but in discrete units. Thus, fuel consumption per ton-mile is expected to decrease with train size. Although unit trains are generally larger than other trains, train service affects fuel economy in ways other than size. Unit trains do not switch enroute; nor do they require yard classification. Thus, a unit train is expected to be more fuel efficient than a through or way train even when hauling the same tonnage.

Formal definitions of train service are given in Schedule 755 of the R-1 report where STB defines a way train as one operated "primarily to gather and distribute cars in road service and move them between way stations or way points.@ In comparison, through trains operate Abetween two or more major concentration or distribution points.@ A unit train is defined as:

> *... a specialized shuttle type service in equipment (railroad or privately owned), dedicated to such service, moving between origin and destination. The applicable contracts or tariffs generally require that a specific tonnage or quantity of carloads be tendered as a unit for shipment on one bill of lading or other shipping document in a solid train for movement between origin and destination.*

A way train trip may be related to a prior or subsequent through train move. However, it is possible for a railroad movement to consist exclusively of way train service. For example, a short trip to a barge transfer facility or an interchange point with another railroad may require only way train service. For purposes of statistical analysis, the distinction between way and through train service is plausible since the railroad is the data observation (not the origin-destination movement). Clearly, a railroad may substitute unit train for non-unit train service, and vice-versa.

The three train types are the basis for data organization by the railroads. They reflect many variations in conditions that affect fuel consumption such as train size, speed change cycles, frequency of yard switching, etc. However, they do not capture physical or network factors that influence fuel use. Although detailed data on grade, curvature, and climate are not available for this study, "railroad effect" variables are included in the model. They consist of the indicator or "dummy" variables described earlier. The indicator variables shift the intercept of the regression line and in doing so represent each railroad's unique system factors (such as grade and climate). They should not be interpreted as constants, fixed costs, or fixed levels of locomotive fuel consumption. They simply capture unexplained effects and improve the predictive capabilities of the model.

General Model

The general formulation of the model is shown in equation (2). In this model, annual gallons of fuel consumed is a function of three GTMC activity levels, time (T), and a set of railroad indicator variables.

$$(2) \qquad FG = f(GTMC, T, RR)$$

The statistical relationship between gross ton-miles and fuel consumption is expected to be linear and positive. The data plot shown in Figure A.1 (appendix) illustrates a strong linear relationship. Because all three GTMC variables are of the same denomination, their coefficients should be directly comparable. While the GTMC variables affect the slope of the regression line, the indicator variables are expected to shift the Y-intercept. Their coefficients could be positive or negative. When several indicator variables relate to the same railroad system (such as the UP or BNSF), their values must be summed before an overall sign or direction can be ascertained. The variable T (time) is expected to have a negative sign indicating increased fuel efficiency over time as a result of newer, more efficient locomotives being added to the fleet, as well as other technological and operational changes that are not reflected in the merger variables.

Serial Correlation and Corrective Procedure

The initial results suggested that serial correlation may exist in the data set. Serial correlation is encountered most often when using time series or pooled data. A major assumption of the linear regression model is that any value of the dependent variable is statistically independent of any other value of the dependent variable; i.e., the error terms of the model are statistically independent. Even when autocorrelation exists, the parameter estimates are unbiased. However, the standard errors of the estimates are biased. Therefore, hypothesis tests may not turn out as expected.

Because of the suspected serial correlation, an autoregressive correction procedure was used to estimate the fuel consumption models. The SAS procedure —Autoreg—corrects for serial correlation by incorporating the residuals from previous observations into the regression model for the current observation. The interpretation of a corrected model is essentially the same as the interpretation of an uncorrected model. The autoregressive procedure is discussed in greater detail in the appendix.

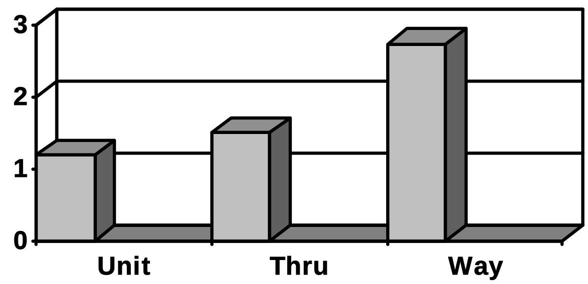
Illustrative Class I Railroad Model

The intent of this study is to estimate a model including railroad variables. However, the model becomes cluttered with 18 independent variables and loses some of its illustrative value. For illustrative purposes, the fuel consumption model is estimated first without the railroad variables. The objectives of this preliminary model are to: illustrate how RTMG vary with type of train service and show the general relationship of way, through, and unit train fuel economies to the published industry average. In this form, the parameter values are estimates of how much Class I railroad fuel use would change with per-unit changes in gross ton-mile activity levels, without accounting for individual railroad effects. Thus, the parameter estimates cannot be used to forecast energy consumption for specific origin-destination movements.

Because fuel use is expected to vary directly with traffic, a "no-intercept" option is selected. In the preliminary model, time is defined as a variable of descending order. This is an unusual approach, but the reason will become apparent soon. For the last year in the series (1998), time assumes a value of zero. For 1997, time assumes a value of 1, for 1996 time assumes a value of 2, etc. In this representation, the value of time for each past year is the number of years removed from the current (last) year in the series. This definition has no effect on the parameter estimates for time or the gross ton-mile variables. The sign of the time variable is simply reversed — i.e., it's positive instead of negative.

As shown in Figure 1, the estimates for the three GTMC variables are: 1.18 for unit trains, 1.50 for through train service, and 2.74 for way train service. The p-values for all three GTMC variables are less than .01, meaning that the t-statistics are highly significant. The parameter estimates represent the expected change in annual fuel use for a one unit increase in gross ton-mile activity while all other effects are held constant. The gross ton-mile variables are measured in thousands. Thus, the parameter estimate of 2.74 for way train gross ton-miles (WTGTM) implies that an additional thousand GTMC in way train service would increase fuel use by 2.74 gallons. In comparison, a similar increase in through train gross ton-miles would increase fuel consumption by 1.50 gallons, while each additional thousand GTMC in unit train service would increase fuel use by 1.18 gallons.

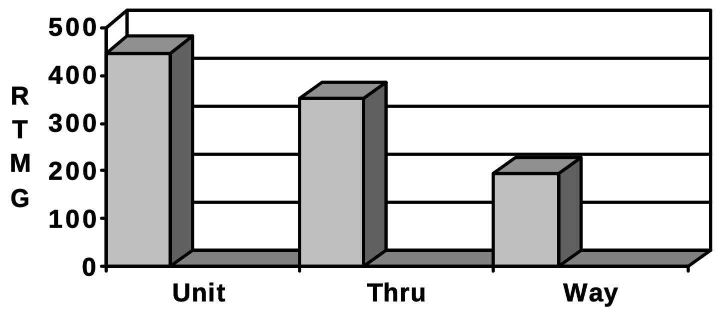
Figure 1. Parameter Estimates for GTMC Model Without Railroad Effects (Gallons per Thou. GTMC)



The model has an R-square of .982, meaning that it explains 98.2 percent of the variation in fuel consumption. Although the results are encouraging, they are not especially useful. The predictions are in gallons per thousand gross ton-miles, but the desired denomination is revenue ton-miles per gallon. Fortunately, the coefficients of this model can be readily converted to RTMG estimates for 1998. Because of the way the time variable was defined—i.e., T assumes a value of zero for 1998— it disappears from the equation. Without an intercept term, the three GTMC variables can be manipulated directly and converted to RTMG values. The inverse of gallons per gross ton-mile is gross ton-miles per gallon. Gross ton-miles per gallon can be converted to revenue ton-miles per gallon using the average net-to-gross train weight ratio. For example, the net-to-gross ratio for a unit grain train of 100-ton covered hopper cars with an average tare weight of 31.5 tons and an empty-return ratio of 2.0 is computed as: 100/(31.5*2+100) = 0.63[7]

The results of the conversion are shown in Figure 2. Apparently, the conversion process works as intended. As noted earlier, the mean RTMG for the Class I industry was 384 in 1998. As Figure 2 shows, the RTMG estimates for Class I railroads are 446, 352, and 193 for unit, through, and way train service, respectively. When these values are multiplied by the percentages of gross ton-miles in each train class, the predicted value of 379 RTMG is within 1 percent of the industry mean.

Figure 2. Estimated Average RTMG for Class I Railroads, by Train Service



The purpose of this preliminary model has been to illustrate the range in railroad fuel efficiency across train service classes. As Figure 2 illustrates, unit train fuel efficiency is substantially greater than the mean, while the fuel efficiency of way train service is substantially less than the mean. The estimated fuel efficiency for through train service is substantially greater than the fuel efficiency of way trains and is within 10 percent of the industry mean. These values and relationships make sense in light of the known industry mean (of 384 RTMG) and the expected relationships discussed earlier. With this background illustration, the report now returns to the main objective of this section— estimating the railroad effects model introduced in equation (2).

Railroad Effects Model

In this model, time is defined as a variable of ascending order and all of the railroad variables described earlier are included as explanatory variables. As in the preliminary model, an autoregressive correction procedure has been used (see appendix). Figure 3 summarizes the parameter estimates of the railroad effects, while Figure A.2 of the appendix provides detailed results from the SAS Autoreg procedure. As the p-values indicate, all three gross-ton mile variables are statistically significant, as are many of the railroad indicator variables. All traffic variables have the expected (positive) signs– i.e. an increase in gross ton-miles will increase fuel consumption. As in the case of the preliminary model, the relationships among the parameter estimates are most important (Figure 4).

As Figure 4 shows, the parameter estimates for the railroad effects model exhibit the same relationships as the estimates from the preliminary model, except they are lower. This is expected since the individual railroad variables are capturing network effects that were not accounted for previously. As noted earlier, the parameter estimates for the GTMC variables represent the expected change in annual fuel use for a unit increase in activity while all other effects are held constant. Thus, the parameter estimate of 2.2 for way train gross ton-miles (WTGTM) implies that an additional thousand GTMC in way train service would increase fuel use by 2.2 gallons. In comparison, a similar increase in through train gross ton-miles would increase fuel consumption by .86 gallons, while each additional thousand GTMC in unit train service would increase fuel use by .70 gallons.

As shown in the appendix, this model has excellent statistical properties. It has a regression R-square of .997— meaning that the variables explain 99.7% of the variation in railroad fuel consumption— and a low coefficient of variation (CV). The CV is a measure of model precision. It is the model error taken as a percentage of the dependent variable mean. The value of 5.4 shown in Figure A.2 means that the root mean square error of the model is very small in relation to the dependent variable mean. The model fits the data well. Moreover, the Durbin-Watson statistic for the corrected model is 2.09.

Validation of Fuel Consumption Model

Just because the model explains most of the variation in fuel consumption does not necessarily mean that it will be a good predictor of fuel use. Since the model includes railroad effect variables, it can be used to predict values for each railroad. A good initial test is to predict the mean period value for each railroad using the carrier's own mean gross ton-mile values.

Table 11 shows predicted and actual fuel consumption values using mean period gross ton-mile values while setting the time variable equal to year 5. As the table shows, the model predicts accurately for each railroad. The highest prediction error is 2.1 percent. The prediction errors for 6 of the railroads are less than 1 percent.

Figure 3. Parameter Estimates and Statistical Tests for Model 1

Gallons of Fuel Consumed As a Function of Unit Train Gross Ton Miles (UTGTM), Through Train Gross Ton Miles (TTGTM), Way Train Gross Ton Miles (WTGTM), Railroad Indicator Variables, and Time (T)

Variable	DF	Parameter Estimate	Standard Error	t Ratio	Prob. of >|t|
Intercept	1	22630565	6342472	3.568	0.0006
UTGTM	1	0.702475	0.1260	5.574	0.0001
TTGTM	1	0.859628	0.1057	8.135	0.0001
WTGTM	1	2.212445	0.8959	2.470	0.0154
BNSF	1	48309287	20068348	2.407	0.0181
ATSF	1	164047501	19013071	8.628	0.0001
BN	1	252906254	38380858	6.589	0.0001
UPSP	1	34309403	22107097	1.552	0.1242
UPCNW	1	7020651	22463351	0.313	0.7554
SP	1	174285955	20327262	8.574	0.0001
UP	1	232620528	34927716	6.660	0.0001
CNW	1	8180228	8475702	0.965	0.3371
KCS	1	141479	6663893	0.021	0.9831
SOO	1	-8470059	7451005	-1.137	0.2587
CR	1	80218472	19321542	4.152	0.0001
CSX	1	118121455	27615354	4.277	0.0001
GTW	1	-5450163	6922073	-0.787	0.4332
NS	1	103449913	22984636	4.501	0.0001
T	1	-611776	860547	-0.711	0.4790

Figure 4. Parameter Estimates for GTMC Model: With and Without Railroad Effects

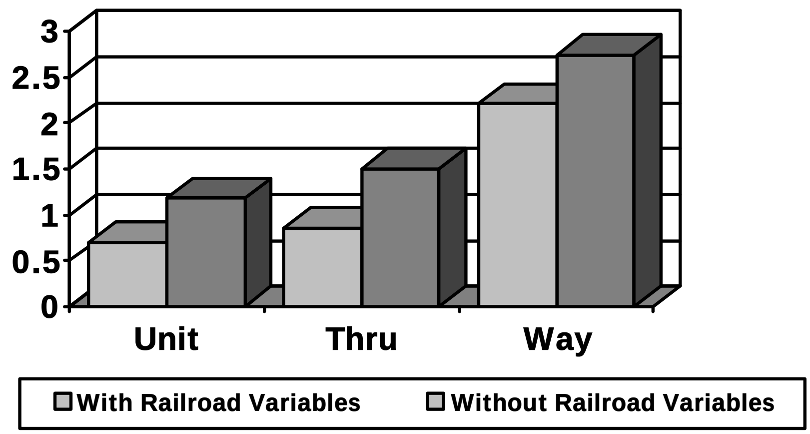


Table 11. Actual and Predicted Gallons of Fuel for Class I Railroads Using Model 1			
Railroad	**Actual Fuel Gallons (000)**	**Predicted Gallons (000)**	**Prediction Error As Percent of Actual**
BN	993,384	1,014,282	-2.10%
CR	269,179	272,017	-1.05%
CSX	407,139	404,949	0.54%
GTW	28,171	28,374	-0.72%
ICG	53,076	52,856	0.41%
KCS	45,168	45,441	-0.60%
NS	324,997	325,569	-0.18%
SOO	53,670	52,917	1.40%
UP	1,099,092	1,103,222	-0.38%

The next logical step is to use the model to estimate revenue ton-miles per gallon for each type of train service. This process is much more cumbersome than before, when the model did not include railroad variables. Because the GTMC coefficients cannot be manipulated directly, there is no straightforward way to convert the parameter estimates to RTMG. Thus, a two-step process is used. First, train service fuel consumption factors are estimated by alternately setting two of the gross ton-mile activity variables to zero and substituting the railroad's actual gross ton-miles for the third one. For example, way and through train activity levels are set to zero and GTMC is substituted for unit train GTMC. In this case, the model predicts the gallons of fuel consumed if all of a railroad's gross ton-miles occur in unit train service. The railroad indicator variables still control for individual railroad effects. Thus, the predicted value is specific to a railroad. Each railroad's predicted value is then divided by its GTMC to estimate a fuel consumption rate for unit train service. This process is repeated alternately for through and way train service and the results are evaluated empirically.

The predictions are in gallons per thousand gross ton-miles, which are easily converted to gross ton-miles per gallon. The GTMC/gallon estimates are then converted to RTM/gallon using the net-to-gross ratio for each railroad. Table 12 shows the results of the conversion process. The prediction error shown in the last column is the difference between the weighted predicted value and the actual RTMG for each carrier.[8] Unlike the error shown in Table 11, the prediction error in Table 12 may reflect model error and/or bias introduced by the two-step conversion process. Nevertheless, the prediction errors are less than 1.5% for all carriers except the Soo Line and CSX.

The prediction errors for each railroad and year are shown in Appendix B. For forecasting purposes, 1998 is the prime year of interest. As Table B.1 shows, Model 1 predicts very well throughout the period for BN, UP, ICG, CR, NS, and ICG. All of the prediction errors are less than 10% and most of them are less than 5%. The highest prediction errors occur for the KCS and Soo Line. The prediction errors for the KSC range from 15 to 23 percent for all but one year of the period. Although the prediction errors for the Soo Line are low during the first half of the period, they range from 12 to 24 percent during the last 4 years.

What constitutes an acceptable level of prediction error is subjective and depends upon the purpose of the forecast. In this study, considerable precision is required. Moreover, the multi-step conversion process may be introducing unknown biasing into the RTMG estimates. For these reasons, a prediction error of 10 percent or greater is unacceptable. Naturally, lower errors are preferred. The 1998 prediction errors for the GTMC model are less than one percent for BN, UP, CR, and GTW, and only 1.7 percent for ICG. Likewise, the 1998 errors are acceptable for NS and CSX – 5.4 and 6.1 percent, respectively. However, the prediction errors for the Soo Line and KCS are unacceptable. Therefore, Model 1 will not be used to forecast values for these two railroads.[9] It is used to illustrate value ranges for the railroads of primary interest in the next section.

Table 12. Predicted Mean Revenue Ton-Miles per Gallon by Type of Train Service Using Model 1

Railroad	Predicted Revenue-Miles per Gallon			Prediction Error As Percent of Actual
	Way Train	Through Train	Unit Train	
BN	192	352	390	0.60%
CR	182	340	407	-0.62%
CSX	190	386	439	-3.35%
GTW	138	240	253	1.41%
ICG	209	396	428	-1.31%
KCS	195	349	362	1.15%
NS	214	369	427	-1.01%
SOO	246	478	558	-9.38%
UP	186	353	394	-1.46%

Illustrations of Railroad Fuel Efficiency Using GTMC Model

The 1998 values generated from Model 1 are shown in Table 13. To summarize, the predicted revenue ton-miles per gallon range from 156 in a GTW way train to 484 in an ICG unit train. Unit train values for BN and UP are 437 RTMG and 410 RTMG, respectively.

Table 13. Estimated 1998 Revenue Ton-Miles per Gallon by Type of Train Service Using Model 1

Railroad	Predicted Revenue-Miles per Gallon			Prediction Error As Percent of Actual
	Way Train	Through Train	Unit Train	
BN	200	389	437	-0.14%
CR	185	364	439	-0.88%
CSX	188	391	446	-6.09%
GTW	156	317	360	-0.80%
ICG	220	440	484	-1.68%
NS	215	392	446	-5.42%
UP	188	365	410	-0.34%

The GTMC model provides useful “landscape” data and illustrates how RTMG vary with train service and railroads. It suggests that fuel efficiencies for way train movements are considerably below the mean, while unit train fuel efficiencies are significantly higher than the mean. However, the railroad effects model does not predict accurately for two railroads. Moreover, it collapses many different types of traffic into three train service categories. This could be problematic as previous studies have shown that TOFC trains are less fuel-efficient than coal or grain unit trains, primarily because of their lower net-to-gross weight ratios. To the extent that a railroad's unit train service includes a significant percentage of TOFC trains, the values shown in Table 13 may understate the fuel efficiency of a large grain or coal unit train. Finally, the conversion process necessary to generate RTMG values is cumbersome in the case of the railroad effects model. A more straightforward forecasting approach with this model is to: (1) estimate the annual fuel consumption for a given railroad using its 1998 way, through, and unit train GTMC values, (2) estimate the incremental way, through, and unit train GTMC attributable to the incremental traffic, (3) add the incremental way, through, and unit train GTMC to the railroad's 1998 values to estimate the without-project activity levels for each train class, (4) predict annual fuel consumption using the without-project GTMC estimates, and (5) take the difference as the annual change in railroad fuel consumption. However, this approach does not remove the other limitations noted above.

The second model presented in this report addresses many of the limitations of Model 1 (the GTMC model) and provides more specific information for assessing the fuel efficiencies of contested waterway traffic. Model 2 eliminates the need for any conversions by directly estimating revenue ton-miles per gallon. Moreover, the logic of the model is consistent with Model 1; in fact, Model 2 is derived from the GTMC model.

4. A STATISTICAL MODEL OF REVENUE TON-MILES PER GALLON

As noted earlier, GTMC actually consists of two components: tare ton-miles and revenue ton-miles. Thus, Model 1 could be restated as:

$$(3) \qquad FG = f(RT * LTM + TT * TM)$$

Where:

RT	=	Average Revenue Tons per Train
TT	=	Average Tare Tons per Train
LTM	=	Loaded Train Miles
TM	=	Round Trip Train Miles

As equation (3) suggests, GTMC is a function of annual train-miles, average train revenue tons, and average train tare tons. It follows that revenue ton-miles per gallon for a train movement can be predicted as a function of the revenue tons per train (RT), the tare tons per train (TT), and the loaded trip miles. To distinguish it from total distance , the last variable is referred to as average length of haul (ALH).

Model 2: Formulation and Results

In Model 1, a linear functional form was used. All three traffic variables were of the same denomination: gross ton-miles. This is not the case for Model 2. ALH is in units of miles, RT and TT are in units of tons. Because of the mixture of units, Model 2 is formulated as a logarithmic function. Log functions are widely-used in transportation and economic analysis. One advantage of this functional form is that the parameter estimates can be interpreted as elasticities— i.e., the percentage change in the dependent or response variable given a one percent change in the level of an independent variable.

The parameter estimates and p-values for Model 2 are shown in Figure 5. All four traffic variables are highly significant with p-values of less than .01 The time (T) is also highly significant. It shows that fuel efficiency (i.e., RTMG) has increased at an average rate of 1.95 percent between 1989 and 1998. As expected, the log of revenue tons per loaded train-mile (LREV) is positive. Increasing the revenue tons in a train increases fuel consumption at a lesser rate than it increases revenue ton-miles. The log of tare tons per train-mile (LTARE) is negative— i.e., increasing tare tons while holding revenue tons constant increases fuel consumption without increasing revenue ton-miles. The relationship between the two parameter estimates is also important. The estimate for LREV is .42 in comparison to -.33 for LTARE. Thus, adding cars of like kind to a train with the same net-to-tare ratio will increase RTMG. Consequently, the model will predict greater fuel efficiency for a 100-car train of covered hoppers cars than for a 75-car train of the same cars. The log of average length of haul (LALH) has a positive sign showing economies of utilization or distance. A threshold level of fuel is consumed in switching and terminal operations irrespective of distance. Increasing the length of haul spreads or distributes the terminal fuel consumption over more revenue ton-miles. Moreover, short trips are more likely to be way train movements which exhibit the poorest fuel economy.

As Figure A.3 shows (Appendix A), Model 2 has excellent statistical properties. It explains 94 percent of the variation in fuel efficiency and the coefficient of variation is less than 1. The DW statistic has been greatly improved and statistical tests show no evidence of other potential problems such as heteroskedasticity.

Figure 5. Results and Parameter Estimates of Model 2

Log of Revenue Ton-Miles per Gallon As a Function of the Log of Rev. Tons per Train (LREV), Log of Tare Tons per Train (LTARE), Log of Average Length of Haul (LALH), Railroad Indicator Variables, and Time

Variable	DF	Parameter Estimate	Std. Error	T-Ratio	Prob. of > |T|
Intercept	1	2.883718	0.8473	3.403	0.0010
LREVTON	1	0.419565	0.1140	3.680	0.0004
LTARE	1	-0.330859	0.1130	-2.927	0.0043
LALH	1	0.374356	0.0759	4.933	0.0001
BNSF	1	0.478300	0.0985	4.854	0.0001
ATSF	1	-0.566800	0.0929	-6.100	0.0001
BN	1	-0.301441	0.0700	-4.309	0.0001
UPSP	1	0.425177	0.0980	4.340	0.0001
UPCNW	1	-0.185472	0.0639	-2.903	0.0047
SP	1	-0.518807	0.0834	-6.222	0.0001
UP	1	-0.344101	0.0825	-4.169	0.0001
CNW	1	0.211314	0.0377	5.609	0.0001
KCS	1	-0.101502	0.0245	-4.150	0.0001
SOO	1	0.022080	0.0303	0.729	0.4677
CR	1	-0.124029	0.0531	-2.335	0.0218
CSX	1	-0.082535	0.0459	-1.800	0.0753
GTW	1	-0.219896	0.0753	-2.920	0.0044
NS	1	-0.135665	0.0377	-3.600	0.0005
T	1	0.019500	0.00246	7.930	0.0001

Predictive Capabilities of Model 2

Table B.2 of Appendix B lists the prediction errors for each railroad and year. As the table shows, the model is a good predictor for all railroads. The prediction error exceeds 10% in only 8 of 90 cases; and the largest prediction error is 12.4 percent. The 1998 prediction errors are less than 5 percent for UP, BN, ICG, NS, and CR. As discussed later, these are the only railroads used in the fuel consumption analysis.

Apparently, the direct estimation approach provides greater precision in that it does not require a conversion from gross ton-miles to revenue ton-miles. Moreover, the separation of GTMC into revenue ton-miles and tare ton-miles seems to improve the model's precision and offers considerable flexibility in forecasting. The model's forecasting capabilities are illustrated in Table B.3 of the Appendix B where several hypothetical movements are analyzed:

- A 150-mile 25-car grain way train movement, such as that which might occur from an elevator to a local processor or river port;

- A 150-mile mixed freight way train trip, such that which as might occur in a long consolidation or distribution movement;

- TOFC (COFC) through train movements of 400 and 800 miles in stand-alone double-stack well cars with an average net weight of 15 tons per container;

- Mixed through freight train movements of 400 and 800 miles with an average load factor of 75 tons per car;

- Grain 75-car through or unit train movement of 400 and 800 miles, such as that which might occur in shuttle train service or when three 25-car shipments are blocked together at origin.

As Table B.3 shows, estimates for the COFC trains range from 231 to 453 RTMG for movements ranging from 400 to 800 miles. In comparison, the mixed freight train estimates range from 309 to 605 RTMG for the same distances. The grain through/unit train forecasts range from 349 to 682 RTMG for distances of 400 to 800 miles. Finally, Model 2 forecasts way train fuel efficiency ratings from 219 to 331 RTMG for a 150-mile movement.

The TOFC estimates from Model 2 are similar to the range of double-stack estimates in the FRA study (Table 7). The model's through and unit train estimates are similar to the mixed freight train ranges in the FRA study, but somewhat lower. As noted earlier, the through train simulations in the FRA study mostly reflect loaded cars while the simulations from Model 2 reflect the empty car tons attributable to the revenue load. Thus, the range from Model 2 was expected to be somewhat lower than the FRA range. The high-end grain through/unit train estimates generated from Model 2 overlap the lower end of the Gervais-Baumel range (Table 9).

Data Ranges and Forecasting

The scenarios in Appendix B illustrate the flexibility and potential uses of the model. However, it has some important limitations which must be mentioned. In the data set, ALH ranges from 180 to 970 miles, while the maximum value for revenue tons is approximately 7,000. The upper range is slightly lower than the 75-car unit grain train scenario analyzed in Appendix B. The highest within-range estimate for a unit train moving 970 miles on the Illinois Central is approximately 735 RTMG.

Some uncertainty exists when predicting beyond the data ranges of independent variables. Although Model 2 is an excellent predictor, relationships among variables could change outside of the data range. A prudent approach would allow for some forecasting beyond the data range; but not much. In this case, it seems prudent to specify a distance range of 150 to 1,000 miles as the predictive limits of the model. Thus, a movement of more than 1,000 miles would have the same predicted fuel efficiency as a 1,000-mile movement. Similarly, a way train movement of less than 150 miles would have the same fuel efficiency as a 150-mile movement.

Additional information exists that may be helpful in evaluating an appropriate range of train weights. In a detailed study of western coal unit trains, the AAR estimated that shifting from 263,000-pound to 286,000-pound cars would result in approximately a 6 percent savings in fuel. In comparison, Model 2 predicts about a 4.5 percent increase in shifting from 100-ton to 110-ton hopper cars. The comparison suggests that predictions at the high-end of the data range of Model 2 are producing fairly reasonable results. Given this additional information, it seems reasonable to use the model to forecast slightly beyond the maximum revenue tons in the data set, such as was done for the 75-car grain unit train. For purposes of this study, a unit train movement of more than 7,500 tons will be assumed to have the same efficiency rating as a 7,500-ton unit train.

In summary, the purpose of Sections 2 and 3 of the report has been to analyze railroad fuel efficiency patterns and identify a range of reasonable estimates. Many studies and approaches have been reviewed, dating back to the rail planning models of the 1970s and the development of train performance simulators. In addition, two statistical models were estimated from Class I railroad data. Both models are good predictors, although Model 1 cannot be used to predict for the Soo Line and KCS. However, Model 1 can provide useful information about way train fuel efficiencies for many railroads and can be used to supplement forecasts from Model 2. Finally, the Gervais-Baumel study provides valuable information about potential railroad fuel efficiency for unit grain train movements.

4. ESTIMATION OF ENERGY CONSUMPTION FOR INVESTMENT ALTERNATIVES

The results of the energy analysis are presented in this section of the report. The barge fuel consumption factors presented earlier are used to estimate waterway fuel consumption while Model 2 is used to estimate railroad fuel use. The railroad estimates reflect considerable detail regarding the characteristics of railroad movements and the carriers involved.

Allocation of Railroad Shipments to Train Classes and Carriers

The 1998 public waybill sample was used to analyze current patterns of railroad movements in the Upper Mississippi Basin. The origin regions provided by the Corps were correlated with Business Economic Analysis (BEA) areas. The BEA is the geographic indicator used on the waybill sample. Only river basin BEA areas were used in the study. For example, the only BEA areas selected from the state of Illinois are those adjacent to the Illinois waterway. The waybill sample uses the Standard Transportation Commodity Code (STCC). In this study, each sample movement was match to the commodity definitions provided by the Corps. A good correlation exists between the STCC and Waterborne Commerce Codes at high levels of aggregation — e.g., Agricultural Products. Therefore, inconsistencies among commodity codes is not a major issue for this study.

The waybill sample was not used to forecast railroad traffic. Its only purpose in this study was to provide a description of current railroad shipment characteristics in the Upper Mississippi region. The primary characteristics of interests were: the percentage of tons moving in each level of train service, the number of cars in the shipment, the average load per car, and the average tare or light weight per car. The last three variables determine the revenue and tare weight inputs to Model 2.

The tables in Appendix C illustrate the results of the waybill analysis for Farm Products and suggest how the information is used in this study. As the appendix shows, the average number of cars in a shipment are shown for each of five potential waybill strata. The car net and tare weights are not shown in the tables, but are computed in the same manner as the number of cars. The percentage shown in the tables is the weighted-average percent of tons moving in each strata, from each origin region to each destination. In the case of Farm Products, the results are heavily weighted by corn and soybean movements. For these shipments, the rail car net weight in 1998 was approximately 100 tons and the tare weight was 31 tons per car.

The strata percentages are used to estimate the proportion of contested waterway traffic that would move in various railroad train service categories. For strata 5 and 6, the cars in the shipment is assumed to constitute a unit or solid train, and thus the revenue and tare ton inputs needed for Model 2 are computed directly from the tables illustrated in Appendix C. Shipments in strata 1-3 are non-unit train movements and thus are assumed to move in through and/or way trains. In these cases, the railroad's average through and unit train weights are used to estimate the revenue and tare ton inputs needed for Model 2, and each railroad's average way train distance is used to estimate the way train miles in non-unit train strata. In most cases, the alternate railroad routes cover long distances. For example, the average assumed grain haul is approximately 1,450 miles for farm products. Thus, the percentage of assumed way train miles is very small and way train effects play a relatively minor role in most of the movement analyses.

In essence, the approach used in this study allocates the incremental tons in each commodity group to railroad shipment categories or strata, then estimates the fuel consumption within each strata and sums or weights the results. The underlying calculations also reflect the railroads involved in the movement. Each origin region was matched to one or more carriers that were assumed to originate and terminate the traffic within that region. For example, movements originated in Region 1 (Illinois) were assigned to the ICG. Movements originated in Iowa and Missouri were assigned to the UP, while movements originated in MN were assigned to the BNSF. However, the destination also affected the assignment of carriers. For example, the ICG cannot move corn or soybeans to the Pacific Northwest. Consequently, Illinois shipments to the PNW were assigned to the UP. Movements to and from eastern regions were assigned to ICG or NS. The assignment of traffic to railroads may not be a perfect match. However, given the level of data aggregation, the process appears to work fairly well.

In most cases, the sample waybill data reflect efficient railroad movement patterns. For example, approximately 80% of the Farm Products tons shipped from Iowa BEA areas to the Pacific Northwest moved in100-110 car blocks. Similarly, the observed farm products shipments from Iowa to California, the Gulf Coast, and Lower Mississippi Valley regions consist predominantly of unit train and large multiple car movements. The distribution of railroad movements among the shipment strata may change in the future especially for Farm Products. However, the net effect of these changes is unclear. The percentage of export corn and soybean movements in unit train service may increase. However, domestic shipment patterns may not change appreciably, or may change in different ways. For example, increased emphasis on value-added processing, identity-preserved shipments, and specialty markets may mitigate against larger shipments in some marketing channels. As a practical matter, most the of affected commodities in the study region already are moving in the large multiple-car and unit train strata. Because the statistical model is estimated from current and historic data, it cannot predict much greater railroad energy efficiencies without violating the underlying data range. Furthermore, the waterway energy factors described earlier in the report are largely based on observed data. As discussed in the introduction, it is likely that both modes will become more fuel-efficient in the future. Thus, the most-defensible basis for comparison is the currently observed values for each mode.

Results of Fuel Analysis

The results of the 2015 fuel analysis are summarized in Table 14. The discussion views the incremental tons as increased waterway traffic that would result from the proposed investments. In essence, a proposed waterway improvement would result in an increase in waterway traffic and a decrease in the traffic of the alternate mode—i.e., railroads. To the extent that waterways are more energy efficient than railroads, the improvements would result in a decrease in fuel consumption. A negative value in a table means that shifting traffic away from railroads would increase energy consumption.

Table 14 shows the estimated annual decrease in fuel use at projected 2015 traffic levels resulting from each of the proposed waterway improvements. The gallons of fuel consumed in waterway transport are estimated by using revenue ton-mile per gallon estimates obtained from TVA and USACE, along with incremental waterway ton-mile estimates of various commodities provided by the Corps. The gallons of fuel used in rail transport are estimated from the statistical model presented earlier and reflect the carriers involved, the destinations and distances, the commodities moved, and other estimated shipment characteristics of the rail movements. All units are in thousands.

Table 14. Projected Reduction in Fuel Consumption and Direct Fuel Cost, 2015 (Thousands)

Alternative	Incremental Waterway Tons	Reduction inGallons	Fuel Cost Reduction
A	176	104	$ 59
B	4,807	2,827	$ 1,611
C	7,551	4,383	$ 2,498
D	10,730	6,230	$ 3,551
E	11,035	6,406	$ 3,652
F	11,480	6,624	$ 3,775
G	14,285	8,276	$ 4,717
H	11,812	6,757	$ 3,852
I	5,705	3,356	$ 1,913
J	12,095	6,922	$ 3,946

As Table 14 shows, significant decreases in fuel consumption are projected for most of the proposed alternatives. For example, fuel consumed in moving the incremental tons would be reduced by approximately 8.3 million gallons with project alternative G. Alternatives J and H would reduce fuel use for the incremental traffic by 6.9 and 6.8 million gallons, respectively.

Table 14 also shows the estimated annual reduction in fuel cost (in 1998 prices) at projected 2015 traffic levels resulting from the reduction in fuel use. The cost savings are estimated by multiplying the reduction in gallons by the average cost of fuel per gallon to Class I railroads in 1998.[10] The largest fuel cost savings are for alternatives G, J and H.

Because the costs and rates of each mode reflect fuel use, the values shown in Table 14 are accounted for in earlier NED calculations. The usefulness of the cost data is limited because they do not reflect energy security costs or the costs of equipment and operational changes that might result from significant fuel cost increases in the future. The recent rise in fuel prices illustrates the uncertainties associated with forecasting future fuel costs. Nevertheless, the analysis is useful in the sense that it explicitly shows the difference in fuel use that would occur based on the energy consumption rates of the modes. The changes in fuel consumption for 2030 and 2050 are presented later in a set of summary tables. The report now turns to a discussion of changes in emissions and related pollution costs.

5. AIR QUALITY EFFECTS

The projected reductions in fuel used to transport the incremental traffic will result in reductions in emission levels. The emission levels of all non-road sources are expected to be lower in 2015 than today. Nevertheless, a reduction in fuel consumption will result in some beneficial emission effects. The discussion of air quality effects begins with an overview of baseline emission levels and expected changes in future years. This overview is followed by a discussion of estimating techniques and a presentation of results.

Regulatory Overview

The 1990 Clean Air Act Amendments directed EPA to study the contribution of nonroad engines to urban air pollution, and regulate them if need be. In 1991, the agency released a study that showed higher-than-expected emission levels for nonroad equipment. The EPA study concluded that emissions from nonroad engines are significant sources of oxides of nitrogen (NOx), volatile organic compounds (VOC), and particulate matter (PM). In response, the agency initiated regulatory programs for several categories of nonroad engines.[11]

In April 1998, EPA finalized emission standards for NOx, HC, carbon monoxide (CO), PM, and smoke for locomotives. Then, in August 1998, EPA adopted more stringent emission standards for NOx, hydrocarbons (HC), and particulate matter for new nonroad diesel engines. EPA's intent is to phase in the regulations over several years, beginning in 1999. The standards are expected to reduce NOx emissions by two-thirds and HC and PM emissions (from new nonroad diesel engines) by 50 percent. A unique feature of EPA's locomotive program is that it includes emission standards for remanufactured engines. This is important because locomotives are generally remanufactured 5 to 10 times during their service lives (which is typically 40 years or more).[12]

Locomotive units in-service before 1973 and small railroads are exempt from the regulations. The locomotive emission standards are being implemented in phases for the remainder of the fleet. Three separate sets of emission standards have been adopted. Their applicability depends upon the date the locomotive is first manufactured.

For regulatory purposes, locomotives are grouped into three "tiers" based on the original manufacture date. Locomotives manufactured from 1973 to 2001 comprise Tier 0. Locomotives manufactured from 2002 to 2004 comprise Tier 1. Tier 2 consists of locomotives that will be manufactured in 2005 or later. The locomotive emission standards are applicable at the time of original manufacture and at each subsequent remanufacture date.

EPA has proposed emission regulations for new marine diesel engines (November 1998). If adopted, the regulations would apply to engines manufactured in 2004 and beyond. The proposed emission limits "are similar to emission limits for corresponding land-based nonroad or locomotive engines."[13] In the Final Regulatory Impact Statement, EPA notes that:

> *manufacturers of marine diesel engines typically start with a partial or fully completed land-based nonroad diesel engine … and adapt it for use in a marine environment. The emission standards that apply to land-based nonroad diesel engines therefore serve as the primary basis for the standards that apply to marine diesel engines.*

As Table 15 shows, locomotives are primarily a concern with respect to emissions of nitrous oxides, particulate matter, and volatile organic compounds (VOC) or hydrocarbons. Line-haul units currently emit 270 grams of nitrous oxides per gallon of fuel consumed, while switcher units emit 362 grams of NO_x per gallon.

Table 15. Baseline Locomotive Emissions by Duty Type (grams per gallon)

Pollutant	Line Haul	Switch
NO_X	270.4	361.9
PM	6.7	38.1
HC	10.0	21.0

Source: U. S. Environmental Protection Agency, Office of Mobile Sources. *Locomotive Emission Standards: Regulatory Support Document*, April, 1998.

As Table 16 shows, locomotives are expected to reduce emissions substantially between now and 2005. New Tier 2 locomotives will emit 62 percent less NO_x per gallon, 50 percent less PM, and 47 percent less hydrocarbons in comparison to baseline emissions.

Table 16. Expected Locomotive Emission Reductions: Line-Haul Duty Cycle		
Pollutant	**Tier 1**	**Tier 2**
NO_X	49%	62%
PM	0%	50%
HC	3%	47%
Source: United States Environmental Protection Agency, Office of Mobile Sources. *Locomotive Emission Standards: Regulatory Support Document*, April, 1998.		

Estimating the Cost of Pollution Compliance

The expected emission rates for locomotives and barges are shown in Table 17. With the exception of sulfur dioxide, the emission rates reflect Tier 2 standards for new locomotives brought into service after 2004. Because emissions are being forecast for 2015, 2030, and 2050, the Tier 2 standards should approach the average emission rates during the period. They are the best estimates now available. The sulfur dioxide rate is derived from a recent USACE report. All emission rates have been converted to pounds per gallon.

Table 17. Expected 2005 Emission Rates for Locomotive and Marine Diesel Engines in Pounds per Gallon					
VOC	**CO**	**NOx**	**PM-10**	**SO2**	**Total**
012	.059	.227	.008	.027	.343
Sources: U. S. Environmental Protection Agency, Office of Mobile Sources. *Locomotive Emission Standards: Regulatory Support Document*, April, 1998; and Marmorstein, Jeffrey. *An Analysis of Air Quality Impacts Resulting From Potential Actions On The Upper Mississippi River – Illinois Waterway Navigation System*, USACE, Sep. 1999.					

The intent of the clean air standards is to force pollution emitters to internalize the costs of reducing emissions to comply with federal regulations. In the initial approach used in this study, it is assumed that incremental pollution resulting from a shift to rail is abated at a cost to the potential emitter (the railroad). A 1999 study by the U.S. Environmental Protection Agency quantifies the projected costs of future compliance with the most recent Clean Air Act Amendments and the resulting emission reductions.[14] The study estimates an annual reduction in VOC, NO_x, and PM-10 for railroads of 215,000 pounds by the year 2010 resulting from compliance with the Clean Air Act.[15] Further, the study estimates an annual compliance cost for the locomotive emission reductions of $35 million by the year 2010.[16] The annual compliance costs are divided by the annual reduction in emissions to generate an estimate of the compliance cost per pound. In 1990 prices, this cost is estimated to be 8.1 cents per pound. After placing the estimate in 1998 prices using the GDP implicit price deflator, it becomes approximately 9.8 cents per pound.

Table 18 shows the estimated annual reduction in emissions resulting from each of the proposed alternatives. The reduction in emissions is obtained by multiplying the total emission rate from Table 17 (.343 pounds per gallon) times the difference in fuel consumption for the incremental traffic. The reduced emissions costs in the fourth column are computed by multiplying the estimated rail compliance cost of 9.8

cents per pound by the estimated reduction in emission levels.

Table 18. Projected Annual Reductions in Emissions and Air Pollution Cost, 2015				
	Thousands		Air Pollution Cost in Thousand Dollars	
Alternative	Gallons of Fuel	Pounds of Emissions	Compliance Cost Method	Pollution Damage Cost Method
A	104	36	$ 3.5	$ 104.9
B	2,827	970	$ 95.0	$ 2,856.6
C	4,383	1,503	$ 147.3	$ 4,428.2
D	6,230	2,137	$ 209.4	$ 6,294.7
E	6,406	2,197	$ 215.3	$ 6,472.8
F	6,624	2,272	$ 222.6	$ 6,692.4
G	8,276	2,839	$ 278.2	$ 8,361.9
H	6,757	2,318	$ 227.1	$ 6,827.5
I	3,356	1,151	$ 112.8	$ 3,391.2
J	6,922	2,374	$ 232.7	$ 6,994.0

The results, it should be noted, consider the fact that emission rates will be reduced significantly from current levels and thus will reflect the technology expected to be in place by 2015. Even with this improved technology, there will be incremental emissions associated with the incremental traffic — that is, if the waterway improvements are not implemented, 2015 emissions will be greater in the without-project scenarios. Railroads will burn more fuel than barges to move the same (incremental) traffic and in doing so will emit more pounds of pollutants.

The logic in applying a compliance unit cost to the incremental emissions is that in the without-project scenarios, railroads must keep emissions at the same level with the incremental traffic. In this case, railroads (or manufacturers) must further improve their pollution control technology to keep emission levels the same, given the higher traffic level. It is assumed that the cost of improved technology is approximately equal to the average cost of the technology needed to meet Tier 2 standards; i.e., the average cost of compliance.

If the incremental emissions are not abated by further improvements in emission control technology, or offset by reductions elsewhere, then overall emissions from nonroad sources will increase and there will be a cost to society that is not internalized by the transportation modes. Increased emissions of volatile organic compounds, nitrogen oxides, and particulate matter can have adverse impacts on human health, property, and agricultural crops. Health and property damage costs are associated with increased levels of individual pollutants.

Societal Cost of Increased Air Pollution

The last column of Table 18 shows estimated air pollution benefits using the alternative approach. The results are based on a set of air pollution damage unit costs and adjustment factors used by Federal Highway Administration in the Highway Economic Requirements System (HERS).[17] HERS is used by FHWA and states to analyze the impacts and benefits of transportation operations and improvements. The air pollution damage costs are derived from a widely-cited study by McCubbin and Delucchi (1996) entitled *Health Effects of Motor Vehicle Air Pollution*.[18] The unit costs (Table 19) represent nationwide average damage costs per ton from exposure to main pollutants. The costs for particulate matter and carbon monoxide are adjusted or scaled for use in HERS to reflect various environmental and population settings. The adjustment factors shown in Table 20 reflect the fact that emissions in rural areas are widely dispersed and population densities are relatively low.

Table 19. Air Pollution Damage Costs Used in the Highway Economic Requirements System (Dollars per Ton)

	Moderate	High
NO_X	$ 1,569	$ 3,730
PM	$ 2,492	$ 4,961
VOC	$ 1,084	$ 2,834
SO_2	$ 1,647	$ 8,644

U.S. Department of Transportation, Federal Highway Administration. Highway Economic Requirements System: Technical Report, Version 3.1, March, 1999.

Table 20. Air Pollution Damage Cost Adjustment Factors Used in the Highway Economic Requirements System

	Urban	Rural
NO_X	1.5	1.0
PM	1.0	0.5
VOC	1.5	1.0
SO_2	1.5	1.0

U.S. Department of Transportation, Federal Highway Administration. Highway Economic Requirements System: Technical Report, Version 3.1, March, 1999

The HERS pollution damage factors have been applied in this study in the following way. It is assumed that 90% of the locomotive miles occur in rural areas. Based on this assumption, the appropriate HERS adjustment factors are selected from Table 20 and applied to the unit costs in Table 19. Only the moderate damage costs are used. The adjusted unit costs then are multiplied by the change in emissions from column 3 of Table 18. This approach probably understates the costs in populous non-attainment areas. However, specific data were not available to allow such an adjustment. Even using the moderate cost estimates, the estimated societal costs of emissions associated with incremental traffic is much higher than the compliance cost which is assumed to be internalized by the railroad. For example, the pollution damage benefits (reduction in cost) are nearly $7 million annually for alternative J.

It is important to note that the two cost estimates shown in Table 18 are not additive. Either the railroads keep nonroad emissions at the same level and incur the average compliance cost, or the incremental emissions in the without-project scenarios result in pollution damage costs. Which approach is more realistic cannot be determined without additional analysis and/or assumptions; so, both estimates are presented as alternative views of air quality impacts. A more immediate concern is whether the air pollution costs are included in earlier NED calculations. To some extent, recent railroad purchases of new locomotives reflect the cost of pollution control. Certainly, the cost of locomotives purchased in the future will reflect these costs. If the NED calculations are based on projections of future equipment costs, the compliance costs are at least partly reflected in the modal cost comparison. If the modal cost comparisons are extrapolations of historical costs, the results may not reflect all of the compliance costs. A precise answer to this question depends on the assumptions and data that went into the rail and barge cost/rate comparisons.

6. SAFETY EFFECTS

A shift in mode, origin, or destination may increase the frequency of accidents and accident-related costs. In a discussion of accident risks, it is necessary to distinguish between hazardous material (hazmat) and non-hazmat movements. Generally, accidents are a function of exposure and accident rates. For hazardous material movements, the risk of a spill or release (given that an accident has occurred) is related to the likelihood of a breach of containment. For all types of shipments, accident-related costs are a function of the number of accidents and the type, severity, and environment of the accident. Accident-related costs for non-hazmat shipments consist of three primary categories: property damage, injury, and fatality. Accident-related costs for hazmat traffic may also include the cost of emergency response, health care, evacuation, cleanup, and potential diminution of air and water quality.

The risks and potential implications of hazardous material shipments are analyzed in a separate USACE report – "Analysis of the Impact of Infrastructure Improvements on the Risks of Accidents and Hazardous Spills." The safety analysis in this report will focus on accident costs other than those which might result from a hazmat incident. To the extent that a hazmat release or spill occurs, the property damage unit costs used in this study will understate the cost of the incident. In many cases, rail lines pass through communities in closer proximity to residential areas than do alternate river routes. Thus, potential evacuation and human health care costs may be greater for rail shipments. However, a waterborne hazmat spill has direct implications for water resources, whereas an overland rail shipment may not. Clearly, the change in hazmat-related costs is a function of many factors other than traffic and cannot be analyzed quickly. The aforementioned USACE report concluded that "the risk of hazardous spills increased both on the rail and on the waterway (in the study area) in the without-project future," but that "the small changes in risks … should not be a factor in determining a recommendation for waterway infrastructure investments." Additional inferences regarding hazmat costs will require detailed knowledge of alternate mode routings, chemical (commodity) properties, community risk profiles, and differences in mitigation costs between land and waterway incidents. For these reasons, quantification of hazmat incident costs is beyond the scope of this study.

Approach and Data Sources

The quantification of accident costs is a multi-step process. Annual accident-related costs are estimated for the with-project and without-project scenarios. Without-project accident costs are based on railroad accident factors, while with-project costs reflect waterway accident data. For both the with-project and without-project scenarios, a two-step analysis process is followed: (1) estimate annual accidents, fatalities and injuries for the incremental traffic and (2) multiply the annual events by the applicable unit cost per property damage, fatality or injury.

Information from a 1998 University of Memphis study conducted for the USACE is used to estimate waterway accident costs.[19] The University of Memphis study quantified waterway accident damage costs and injury and death rates per ton-mile for the Upper Mississippi and Illinois waterways. The injury and death rates per ton-mile were then applied to injury and death cost estimates to determine the annual fatality and injury costs. The injury and death unit costs were obtained from the National Safety Council publication, *Accident Facts - 1997.*

To obtain injury and death rates and accident damage costs per ton-mile, the University of Memphis study reviewed a 1996 study conducted by the Transportation Analysis and Research Center for the USACE[20] The 1996 study compiled waterway accident rates on the Upper Mississippi and Illinois waterways. Injury, death, and damage rates were computed from two different accident databases, the CASMAIN database and the MINMOD database. When reviewing these rates, the authors of the University of Memphis study found large discrepancies. The largest discrepancy was in injury rates, where one database showed an injury rate that was 2 percent of the injury rate shown in the other. The 1998 authors found that the discrepancy was the result of one database reporting minor injuries not resulting from accidents (e.g., sprained wrists from winding rope). Thus, for purposes of computing injury rates on the Upper Mississippi and Illinois waterway systems, the 1998 authors used the more conservative estimates, as they found that injury statistics of other modes did not include injuries not resulting from accidents. For purposes of computing death rates and damage costs per ton-mile, the authors used the higher rate from the two databases.

The injury and death rates used in the University of Memphis study are used in this analysis, as are the damage costs per ton-mile. However, the property damage costs have been indexed to 1998 levels. All three waterway accident factors are shown in Table 21.

Table 21. Waterway Injury Rates, Death Rates, and Accident Damage Costs per Ton-Mile

	Upper Mississippi River	**Illinois Waterway**
Injuries per Ton-Mile	0.00000000011	0.000000000023
Deaths per Ton-Mile	0.000000000052	0.000000000058
Damage Cost per Ton-Mile (1998 $)	$0.0002627	$0.000031

Source: University of Memphis, Transportation Studies Institute. *Accidents and Hazardous Spills Analysis for Upper Mississippi River Basin*, Prepared for U.S. Army Corps of Engineers, Rock Island District, September 1998. (Damage Costs placed in 1998 prices using the GDP implicit price deflator.)

In order to estimate the change in waterway accident costs on the Lower Mississippi River system, the University of Memphis study adjusted the accident rates on the Upper Mississippi River by a relative risk factor. The authors examined the ratio of Upper Mississippi River insurance costs to insurance costs on the rest of the waterway system to estimate the risk on the Upper Mississippi relative to the rest of the waterway system. They found that the insurance costs per ton-mile on major segments of the inland waterway network connecting to the Upper Mississippi were 73 percent of the insurance costs per ton-mile on the Upper Mississippi. Thus, they adjusted the injury, death, and damage rates shown in Table 15 by multiplying them by .73 in order to obtain estimates for the lower Mississippi River. The same relationship is assumed to hold true for this study.

Railroad accident data were obtained from the Federal Railroad Administration's Office of Safety Analysis Web Site at http://safetydata.fra.dot.gov/officeofsafety/. Train accident rates, fatality rates, and injury rates were developed utilizing the Summary of Accident/Incident Counts and Summary of Operational Data tables found on the web site. These three rates were calculated and weighted on a million train-mile basis. The rates used in this study are a weighted average for the 1995-1998 time frame. The adjusted dollars per train accident were calculated from the Train Accidents by Type and Major Cause table derived from Form FRA F 6180.54, and from the Summary of Accident/Incident Counts table.

The logic of the railroad accident analysis is that exposure to accidents increases with railroad activity. In this case, train-miles is the appropriate activity measure. Accident damage may increase with the weight of the train. However, the probability of an accident is affected mostly by train speed, traffic control, frequency of grade crossings, visibility, weather, and many operational and human factors. As railroad train-miles increase, the frequency of three major types of accidents will increase as well: (1) highway grade-crossing accidents, (2) trespasser accidents (e.g., people crossing rail tracks at unauthorized locations or trying to obtain illegal rides on freight trains); and (3) train derailments and other types of road train accidents. Worker injuries or fatalities for trainmen and other railroad occupations also may increase with train activity.

Railroad train-miles have been estimated for each movement flow in the study. For unit train strata, the number of train-miles generated from revenue ton-miles is computed directly from the number of cars and tons in the shipment using the empty return ratio— which is assumed to 2.0 for unit train shipments. For all other strata, shipments are assumed to move in through and way trains. For these cases, a train-mile-to-revenue ton-mile ratio has been computed for each railroad and used to convert ton-miles to train-miles. The ratio reflects the average empty-to-loaded mile percentage and thus assigns empty train-miles to each shipment.

Estimates of Fatality and Injury Unit Costs

The unit costs used in this study are estimated by the National Safety Council (NSC) and represent the average costs of fatal and nonfatal unintentional injuries. The NSC uses four categories to classify unintentional injuries: Motor Vehicle, Work, Home, and Public. The cost of a fatality shouldn't vary a great deal across the four categories.[21] However, injury costs may differ substantially among the classifications. Because "Motor Vehicle" is the only transportation-related category published by NSC, it is a logical selection for this study. As noted earlier, many railroad fatalities and injuries result from highway grade-crossing accidents. Thus, motor vehicle fatality and injury costs are the most relevant category for analyzing railroad accidents. For purposes of consistency, the same unit costs are applied to waterway injuries.

NSC recommends the use of "comprehensive costs" for purposes of benefit-cost analysis.[22] Comprehensive costs include economic costs plus a measure of the value of "lost quality of life." The economic components of motor-vehicle injury and fatality costs include wage and productivity losses, medical expenses, and administrative expenses. Wage and productivity losses include the value of wages, fringe benefits, household production, and travel delay. Medical expenses include ambulance and helicopter transport costs. Administrative expenses include the administrative cost of insurance, police, and legal costs.[23]

In 1998, the economic cost components alone totaled to $980,000 for each death and $35,600 for each motor vehicle injury. However, these estimates do not include the "value of a person's natural desire to live longer or to protect the quality of one's life;" i.e., someone's willingness to pay for improved safety. This value has been estimated through empirical studies of what people actually pay to reduce their safety and health risks. When people's willingness to pay to avoid lost quality of life are considered, the estimated unit costs become $3,010,000 per death and $38,200 for a non-incapacitating injury. According to NSC, these comprehensive costs can be interpreted as "the maximum amount society should spend to prevent a statistical death or injury." It should be noted that the NSC unit cost for fatalities is almost identical to the middle-range value for the cost of a statistical death as used by Federal Highway Administration (FHWA) in the national Highway Cost Allocation Study.

Results of 2015 Accident Analysis

Table 22 shows the annual avoided railroad accident damage, fatality, and injury costs resulting from each of the project alternatives, at 2015 traffic levels. Accident damage costs are estimated based on data obtained from the Federal Railroad Administration, while fatality and injury costs are estimated from National Safety Council data on the costs of fatalities and injuries. As Table 22 shows, the estimated total avoided railroad accident costs (damage, fatality, and injury) are quite large for some scenarios; e.g., over $30 million for alternative G. Fatality costs are by far the largest cost of the three accident costs, as the cost of a fatality is estimated at $3 million. As noted earlier, these costs result mostly from grade crossing accidents and illegal track crossings and other acts of trespassing.

Table 23 shows the annual increase in waterway accident damage, fatality, and injury costs resulting from each of the project alternatives, at 2015 traffic levels. These increases are estimated based on projected increases in Upper Mississippi and Illinois waterway ton-miles, river accident rates, and costs of fatalities and injuries obtained from the National Safety Council. As the table shows, while there are some impacts, they pale in comparison to the estimated avoidance of accident costs resulting from reduced rail traffic.

Table 24 summarizes the annual net reduction in total accident costs resulting from each of the proposed alternatives, at 2015 traffic levels. As the table shows, the net reduction is very large for some alternatives; e.g., nearly $27 million under alternative G.

Table 22. Avoided Railroad Accident, Fatality, and Injury Costs in 2015 as a Result of Project Alternatives			
Alternative	Avoided Railroad Accident Costs in Thousands of Dollars		
	Property Damage	Fatalities	Injuries
A	$ 31	$ 342	$ 36
B	$ 821	$ 9,006	$ 955
C	$ 1,278	$ 14,044	$ 1,485
D	$ 1,829	$ 20,073	$ 2,124
E	$ 1,882	$ 20,647	$ 2,185
F	$ 1,948	$ 21,402	$ 2,263
G	$ 2,432	$ 26,666	$ 2,822
H	$ 1,991	$ 21,899	$ 2,313
I	$ 978	$ 10,719	$ 1,136
J	$ 2,040	$ 22,434	$ 2,369

Table 23. Forecasted Incremental Waterway Accident Costs in 2015				
Alternative	Incremental River Accident Costs in Thousands of Dollars			
	Property Damage	Fatalities	Injuries	Total River Accident
A	$ 36.4	$ 29.5	$ 0.6	$ 66.5
B	$ 949.3	$ 777.9	$ 16.1	$ 1,743.2
C	$ 1,486.4	$ 1,219.0	$ 25.2	$ 2,730.7
D	$ 2,126.6	$ 1,741.1	$ 36.1	$ 3,903.8
E	$ 2,187.5	$ 1,790.8	$ 37.1	$ 4,015.5
F	$ 2,270.5	$ 1,859.8	$ 38.5	$ 4,168.9
G	$ 2,825.8	$ 2,314.6	$ 48.0	$ 5,188.4
H	$ 2,327.1	$ 1,908.1	$ 39.5	$ 4,274.7
I	$ 1,132.5	$ 926.8	$ 19.2	$ 2,078.5
J	$ 2,383.8	$ 1,954.4	$ 40.5	$ 4,378.6

Table 24: Net Reduction in Accident, Fatality, and Injury Costs Resulting from Project Alternatives in 2015

Alternative	Accident Costs in Thousands of Dollars		
	Incremental River	Avoided Rail	Net Reduction
A	$ 66.5	$ 409.5	$ 343.0
B	$ 1,743.2	$ 10,781.7	$ 9,038.5
C	$ 2,730.7	$ 16,808.2	$ 14,077.5
D	$ 3,903.8	$ 24,026.0	$ 20,122.2
E	$ 4,015.5	$ 24,713.0	$ 20,697.5
F	$ 4,168.9	$ 25,613.0	$ 21,444.1
G	$ 5,188.4	$ 31,920.0	$ 26,731.6
H	$ 4,274.7	$ 26,202.8	$ 21,928.1
I	$ 2,078.5	$ 12,833.1	$ 10,754.7
J	$ 4,378.6	$ 26,843.3	$ 22,464.7

Caveats Regarding Safety Analysis

It should be noted that the estimation of accident costs is not an attempt to place blame. The preponderance of rail-related fatalities and injuries result from highway-rail grade crossing collisions and from trespassers making illegal and ill-advised track crossings. Indeed, the railroad are blameless in many of these cases. Nevertheless, from a social cost perspective, the injury or fatality is relevant, regardless of who is to blame. It is nearly impossible for a barge to collide with an automobile. Moreover, the concept of trespassing is much different between rail and barge transportation. These differences are simply functions of the ways used and their proximity to pedestrian and drivers.

Many facets of accident-related costs are reflected in railroad and barge casualty and insurance costs, and thus may be reflected in part or in whole in the NED benefits estimated in earlier studies. Most likely, the costs of worker injuries are included in casualty and insurance costs and thus are accounted for already. The answer is not so clear for motor vehicle, trespasser, and other non-worker fatalities and injuries. The liability of the railroads' for grade crossing and trespasser accidents is key to answering this question.

Currently, considerable uncertainty exists regarding liability for grade-crossing accidents. A pending case in the 6th Circuit Court — Shanklin v. Norfolk Southern Corporation — may clarify railroad liability. In the landmark Easterwood v. CSX case, the court appeared to say that railroads are not liable for accidents resulting from inadequate warning or protection devices if they were paid for in part with federal funds. However, other courts have interpreted the Easterwood results differently. Thus, at present, a railroad is not necessarily immune from liability for grade-crossing accidents. Indeed, railroads and/or state transportation departments may be found liable in these cases. Because railroads may be liable for grade-crossing accidents, and because considerable uncertainty exists as to the nature and scope of that liability, it is likely that railroad insurance and casualty costs reflect premiums to insure against injury and fatality claims and settlements for claims brought against the railroads. Therefore, it is likely that much of the accident-related costs would not be additive to NED benefits. To the extent that state governments are held liable for crossing accidents, and the difference between railroad and barge casualty and insurance costs are less than the costs borne by motorists and states, some portion of the accident costs computed in this study may constitute additions to the NED or other account. However, a more detailed analysis is needed before a definitive percentage can be ascertained.

One potential approach is to compare the railroads' actual casualty and insurance costs (as reported in Schedule 410 of the R-1 report) to the estimated costs of fatalities, injuries, and property damage using the unit costs used in this study. Table 25 shows BNSF's 1998 casualty and insurance costs as reported in the railroad's R-1 report. Table 26 shows an estimate of the comprehensive accidents costs for BNSF's entire system and operation in 1998, using the accident rates and costs discussed earlier. As the comparison shows, the estimated comprehensive accident cost is $735 million, which is much greater than the reported casualty and insurance cost of $270 million. This comparison suggests that all aspects of comprehensive accident costs may not be internalized by railroads. However, this example is for one railroad and year only, and therefore may not be a representative comparison. The only conclusion that can be drawn from the example is that a detailed multi-year comparison is warranted for each Class I railroad. Large settlements or spikes in insurance rates could be reflected in a single year's observations.

Table 25. BNSF Casualty and Insurance Cost for 1998 in Thousands of Dollars

Expense Group	**Subgroup**	**Casualty & Insurance Expense**
MW&S	Running	$ 23,904
	Switching	$ 399
	Other	$ 376
	Subtotal	$ 24,679
Equipment	Locomotive	$ 40,656
	Freight Car	$ 21,302
	Other	$ 2,010
	Subtotal	$ 63,968
Transportation	Train Ops.	$ 72,453
	Yard Ops.	$ 99,685
	Spec. Services	$ 903
	Adm. Support	$ 5,674
	Subtotal	$ 178,715
General Adm.		$ 1,837
Total		$ 269,199

Table 26. Estimated Comprehensive Accident Costs for 1998 BNSF Operations			
Cost Category	Accident Rate Million Train Miles	Unit Cost	Estimated Costs (Thou.)
Property Damage	3.13	$102194	$ 52,042
Injury	8.98	$38200	$ 55,812
Fatality	1.28	$3010000	$ 626,851
Total			$ 734,705

7. SUMMARY OF 2015 RESULTS

Table 27 summarizes the annual reductions in emissions costs, fuel costs, and accident costs resulting from each of the proposed alternatives, at 2015 traffic levels using the compliance cost approach to air pollution impact assessment. As the table shows, the total reduction in cost for these three items ranges from a low of approximately $400 thousand under alternative A to a high of more than $31 million under alternative G.

Table 27. Summary of Projected Reduction in 2015 Fuel, Pollution, and Accident Costs Resulting from Waterway Improvements (Using Pollution Compliance Costs)				
Alternative	Net Reduction in Annual Cost (in Thousands of Dollars)			
	Emissions	Fuel	Accident	Total Reduction
A	$ 3.5	$ 59.2	$ 343.0	$ 405.7
B	$ 95.0	$ 1,611.5	$ 9,038.5	$ 10,745.0
C	$ 147.3	$ 2,498.1	$ 14,077.5	$ 16,722.9
D	$ 209.4	$ 3,551.1	$ 20,122.2	$ 23,882.7
E	$ 215.3	$ 3,651.5	$ 20,697.5	$ 24,564.4
F	$ 222.6	$ 3,775.4	$ 21,444.1	$ 25,442.2
G	$ 278.2	$ 4,717.2	$ 26,731.6	$ 31,727.0
H	$ 227.1	$ 3,851.6	$ 21,928.1	$ 26,006.9
I	$ 112.8	$ 1,913.1	$ 10,754.7	$ 12,780.6
J	$ 232.7	$ 3,945.5	$ 22,464.7	$ 26,642.9

Table 28 summarizes the annual reductions in emissions costs, fuel costs, and accident costs resulting from each of the proposed alternatives, at 2015 traffic levels using the pollution damage cost approach. As the table shows, the total reduction in cost for these three items ranges from a low of approximately $507 thousand under alternative A to a high of nearly $40 million under alternative G.

Table 28. Summary of Projected Reduction in 2015 Fuel, Pollution, and Accident Costs Resulting from Waterway Improvements (Using Air Pollution Damage Costs)

	Net Reduction in Annual Cost (in Thousands of Dollars)			
Alternative	**Emissions**	**Fuel**	**Accident**	**Total Reduction**
A	$ 104.9	$ 59.2	$ 343.0	$507.10
B	$ 2,856.6	$ 1,611.5	$ 9,038.5	$13,506.60
C	$ 4,428.2	$ 2,498.1	$ 14,077.5	$21,003.80
D	$ 6,294.7	$ 3,551.1	$ 20,122.2	$29,968.00
E	$ 6,472.8	$ 3,651.5	$ 20,697.5	$30,821.80
F	$ 6,692.4	$ 3,775.4	$ 21,444.1	$31,911.90
G	$ 8,361.9	$ 4,717.2	$ 26,731.6	$39,810.70
H	$ 6,827.5	$ 3,851.6	$ 21,928.1	$32,607.20
I	$ 3,391.2	$ 1,913.1	$ 10,754.7	$16,059.00
J	$ 6,994.0	$ 3,945.5	$ 22,464.7	$33,404.20

8. RESULTS OF 2030 AND 2050 ANALYSIS

Tables 29-32 summarize the results of 2030 and 2050 analyses. Two tables are presented for each future year. The first table for each year shows the results using the compliance cost approach to pollution cost assessment, while the second table for each year shows the results using the air pollution damage cost approach. All costs are in thousands of dollars and are not discounted.

As noted earlier, cautions should be exercised when interpreting these numbers. The change in fuel costs has been accounted for in earlier NED analyses. Part of the air pollution cost has probably been accounted for as well, especially under the compliance cost approach. Moreover, to the extent that accident costs are captured in insurance premiums, some accident costs have been captured by the NED analyses, as well. Finally, more detailed data and analysis is warranted to "firm-up" the conclusions. Nevertheless, the numbers are illustrative of modal comparisons, which is the main objective of this report. The discussion now turns to an assessment of potential noise effects.

Table 29. Summary of Projected Reduction in 2030 Fuel, Pollution, and Accident Costs Resulting from Waterway Improvements (Using Pollution Compliance Costs)

Alternative	Net Reduction in Annual Cost (in Thousands of Dollars)			
	Emissions	Fuel	Accident	Total Reduction
A	$ 2.6	$ 44.0	$ 264.1	$ 310.7
B	$ 109.5	$ 1,856.8	$ 10,661.2	$ 12,627.5
C	$ 172.9	$ 2,932.5	$ 16,774.6	$ 19,880.1
D	$ 259.9	$ 4,407.6	$ 24,998.3	$ 29,665.8
E	$ 267.8	$ 4,540.7	$ 25,758.8	$ 30,567.2
F	$ 289.6	$ 4,911.6	$ 27,983.3	$ 33,184.5
G	$ 327.9	$ 5,560.7	$ 31,598.7	$ 37,487.3
H	$ 299.9	$ 5,084.7	$ 29,060.1	$ 34,444.6
I	$ 124.1	$ 2,104.3	$ 12,094.2	$ 14,322.7
J	$ 308.4	$ 5,229.0	$ 29,884.3	$ 35,421.7

Table 30. Summary of Projected Reduction in 2030 Fuel, Pollution, and Accident Costs Resulting from Waterway Improvements (Using Air Pollution Damage Costs)

Alternative	Net Reduction in Annual Cost (in Thousands of Dollars)			
	Emissions	Fuel	Accident	Total Reduction
A	$ 78.1	$ 44.0	$ 264.1	$386.20
B	$ 3,291.4	$ 1,856.8	$ 10,661.2	$15,809.40
C	$ 5,198.3	$ 2,932.5	$ 16,774.6	$24,905.40
D	$ 7,813.0	$ 4,407.6	$ 24,998.3	$37,218.90
E	$ 8,049.0	$ 4,540.7	$ 25,758.8	$38,348.50
F	$ 8,706.4	$ 4,911.6	$ 27,983.3	$41,601.30
G	$ 9,857.0	$ 5,560.7	$ 31,598.7	$47,016.40
H	$ 9,013.3	$ 5,084.7	$ 29,060.1	$43,158.10
I	$ 3,730.2	$ 2,104.3	$ 12,094.2	$17,928.70
J	$ 9,269.0	$ 5,229.0	$ 29,884.3	$44,382.30

Table 31. Summary of Projected Reduction in 2050 Fuel, Pollution, and Accident Costs Resulting from Waterway Improvements (Using Pollution Compliance Costs)

Alternative	Net Reduction in Annual Cost (in Thousands of Dollars)			
	Emissions	**Fuel**	**Accident**	**Total Reduction**
A	$ 2.1	$ 36.1	$ 223.3	$ 261.6
B	$ 125.0	$ 2,118.9	$ 12,223.4	$ 14,467.2
C	$ 211.0	$ 3,578.5	$ 20,548.3	$ 24,337.8
D	$ 299.8	$ 5,084.5	$ 29,345.5	$ 34,729.9
E	$ 313.6	$ 5,317.4	$ 30,679.6	$ 36,310.5
F	$ 390.4	$ 6,619.8	$ 38,467.3	$ 45,477.5
G	$ 332.9	$ 5,645.2	$ 32,353.5	$ 38,331.6
H	$ 422.9	$ 7,170.7	$ 41,820.7	$ 49,414.2
I	$ 133.9	$ 2,270.0	$ 13,180.8	$ 15,584.7
J	$ 437.2	$ 7,413.4	$ 43,211.8	$ 51,062.3

Table 32. Summary of Projected Reduction in 2050 Fuel, Pollution, and Accident Costs Resulting from Waterway Improvements (Using Air Pollution Damage Costs)

Alternative	Net Reduction in Annual Cost (in Thousands of Dollars)			
	Emissions	**Fuel**	**Accident**	**Total Reduction**
A	$ 64.0	$ 36.1	$ 223.3	$323.40
B	$ 3,755.9	$ 2,118.9	$ 12,223.4	$18,098.20
C	$ 6,343.3	$ 3,578.5	$ 20,548.3	$30,470.10
D	$ 9,012.9	$ 5,084.5	$ 29,345.5	$43,442.90
E	$ 9,425.7	$ 5,317.4	$ 30,679.6	$45,422.70
F	$ 11,734.4	$ 6,619.8	$ 38,467.3	$56,821.50
G	$ 10,006.8	$ 5,645.2	$ 32,353.5	$48,005.50
H	$ 12,710.9	$ 7,170.7	$ 41,820.7	$61,702.30
I	$ 4,023.8	$ 2,270.0	$ 13,180.8	$19,474.60
J	$ 13,141.1	$ 7,413.4	$ 43,211.8	$63,766.30

9. TRANSPORTATION NOISE EFFECTS

Transportation noise is an important social concern. Its consequences can range from annoyance to physical pain and immediate hearing damage. The Noise Control Act of 1972 established a national policy to promote an environment "free from noise that would jeopardize public health and welfare." The act gives the Environmental Protection Agency authority to establish regulations to control noise emissions —including transportation sources—and requires EPA to issue noise standards for vehicles used in Interstate commerce. EPA's noise standards for railroad equipment are discussed later in this section. First, some important considerations in noise analysis are summarized.

Noise Characteristics

Frequency, loudness, variability, duration, propagation, and attenuation are important characteristics of noise. Frequency (pitch) refers to the "tonal quality" of sound. Mathematically, frequency is equal to the speed of sound (measured in meters per second) divided by the wavelength (in meters). It is measured in hertz: equivalent cycles per second. In essence, frequency is the number of oscillations of a periodic sound wave per unit of time. Frequency is important to noise assessment because the human ear does not respond to all frequencies. Thus, sound-level meters usually are equipped with weighting circuits that filter out very low and high frequencies in much the way a human ear would function.

Loudness is defined by sound pressure level (SPL), which is measured in decibels (dB). The decibel is a logarithmic unit. It is calculated from the square of the ratio of the acoustic air pressure (p) to a reference pressure (p_0).

$$(4) \qquad SPL(db) = 10\log_{10}(p/p_0)^2$$

Because the decibel is measured on a logarithmic scale, sound pressure levels from several sources cannot be summed algebraically. Instead, they must be added logarithmically, as shown below.

$$(5) \qquad SPL(db) = 10\log_{10}\left(\sum_i 10^{SPL_i/10}\right)$$

In equation (5), SPL_i represents any partial sound level that sums to a total sound level. Because of the functional form, a doubling of source noise results in only a 3 dB increase in the existing sound pressure level. An example used by Federal Highway Administration illustrates the additive nature of noise levels: Two heavy trucks producing 90 decibels each would combine to produce 93 dB, not 180 dB.[24] On the logarithmic scale, a10-dB change in sound pressure level is perceived by humans as a doubling or halving of sound pressure level.

The A-scale on a sound-level meter is used most often in noise analysis because it best approximates the frequency response of the human ear.[25] In a 24-hour period, A-weighted decibel (dBA) sound levels may range from 30 (very quiet) to 90 (very loud) or greater. Background or residual sound level is about 45 dBA.[26] Table 33 illustrates several transportation and reference dBA noise levels.

Table 33. Illustrative Transportation and Reference Noise Levels	
Noise Event or Reaction	**A-Weighted Decibel Levels**
Community Impact Threshold	55-65
Bus/Truck	80-85
Diesel Locomotive	93-96
Locomotive Whistle	110-120
Physical Pain Threshold	130

Most transportation sound levels vary in time and space. Periodic fluctuations in sound levels typically occur from changes in traffic volumes or isolated occurrences such as the passage of a freight train. Moreover, sound intensity decreases in proportion with the square of distance from the source. Generally, sound levels for a *point source* will decrease by 6 dBA for each doubling of distance.[27] However, a continuous line of vehicles along a roadway becomes a *line source*. Sound levels are propagated all along a line source and overlap at a receiver (i.e., the point of measurement). According to FHWA, noise produced by a highway traffic stream decreases at a rate of 3 dBA for each doubling of distance.[28] Intervening structures, terrain, vegetation, or "soft ground" may serve to decrease sound intensity more rapidly. Considering all of these factors, FHWA suggests that 4.5 dBA is a suitable noise attenuation rate for each doubling of distance from the source.[29]

Although railroad and highway noises are similar in many respects, there are some important distinctions. A long train may be viewed as a line source; however, its duration is short. Moreover, train noise events are intermittent. As a train approaches, passes by, and then proceeds into the distance, the A-weighted sound level rises, reaches a maximum, and then fades into the background noise. For these reasons, railway noise impacts are best analyzed by focusing on single-event noises (rather than continuous noise).

Noise Measures

In addition to the A-weighted sound level, several important noise measures are: Maximum Sound Level (L_{max}) during a single noise event, Sound Exposure Level (SEL), Hourly Equivalent Sound Level, and Day-Night Sound Level (L_{dn}).[30] The SEL describes a receiver's cumulative noise exposure from a single noise event. It is a measure of the total sound energy of an event, taking into account its intensity and duration. SEL often is used to measure noise for a single train event (passage) because it increases with the duration of the event. SEL can be thought of as the sound level that a human would experience if all of the sound energy of an event occurred in one second.[31] Once measured, it can be used to calculate one-hour and 24-hour cumulative descriptors.

L_{dn} describes a receiver's cumulative average noise exposure from all events during a 24-hour period, with events between 10 p.m. and 7 a.m. increased by 10 decibels. This measure was developed in the early 1970s by EPA as an indicator of community noise exposure. The 10-dBA correction factor is added to nighttime noises to account for increased annoyance from loss of sleep.[32] The L_{dn} is commonly used to evaluate noise effects on communities and residential areas. As discussed later, many agencies have adopted an L_{dn} value of 65 dBA as a threshold above which "land is considered incompatible for schools, hospitals, and residential use."[33] However, noise impacts may start at lower dBA levels.

A generalized procedure for analyzing train noise (other than train horns or whistles) is:[34]

1. Divide the railroad right-of-way into line-segments that are fairly homogeneous in terms of train speed, track condition, and other factors;
2. Calculate the SEL for each train passage at a reference distance (e.g., 100 feet), accounting for noise attenuation as a result of barriers, structures, or terrain that might block or shield train noise;
3. Sum the SELs for all track segments in the study area; and
4. Determine L_{dn} values based on train passages in a 24-hour period, with events between 10 p.m. and 7 a.m. being increased by 10 decibels.

Noise Impact and Cost Indicators

The impact of train noise on humans beings depends upon many physical and community factors including: location and density of residential development zones in relation to rail lines, rail traffic levels and characteristics (e.g., train speeds), time of day of train passages, existing noise levels, and how noise increases are perceived in relationship to threshold or reference levels. EPA suggests that a community noise level (L_{dn}) of less than or equal to 55 dBA is "requisite to protect public health and welfare with an adequate margin of safety."[35] A 5 dBA increase in L_{dn} is commonly used as the minimum required for a change in community perception.[36] In its high-speed rail assessment guidelines, FRA suggests that a change from 50 to 55 dBA is assumed to be the lowest threshold where noise impacts start to occur.[37] The Department of Housing and Urban Development (HUD) in its environmental noise standards defines an L_{dn} of 65 as the beginning of a “normally unacceptable noise zone.”[38] Similarly, Federal Aviation Administration (FAA) considers noise environments where the L_{dn} is greater than 65 dBA as “not compatible with residential land uses.”[39]

Quantification of noise costs requires detailed data and/or assumptions regarding the number of households affected, community noise thresholds, and how consumers value noise changes. Federal Highway Administration has developed a generalized procedure for use in highway cost allocation studies. In the FHWA approach, noise cost is a function of the number of affected housing units (HU), the noise level (NL) in decibels above the threshold level (NT), and the change in property values (PROP) per decibel, as described in Equation (6). FHWA assumes the threshold noise level to be 55 dBA, while acknowledging that there are varying opinions on the exact threshold level.

$$(6) \qquad NoiseDamge = HU * (NL_{dBA} - NT_{dBA}) * \Delta PROP_{dBA}$$

The change in property value is a key variable in the noise cost equation, and there is some uncertainty in the estimates used. FHWA employs a range of market estimates (Table 34). The mid-range estimate suggests that a dBA increase above the community impact threshold would result in a .4 percent decrease in property values. However, the high-impact factor suggests that the market value of noise impacts may be much greater.

Table 34. Percent Change in Property Value per dbA Increase Over Threshold	
High-Impact Estimate	.88%
Middle-Range Impact Estimate	.40%
Low-Range Impact Estimate	.14%
Source: Federal Highway Administration. *1997 Highway Cost Allocation Study*.	

The estimates in Table 34 reflect a number of studies conducted in the 1970s and 1980s in various geographic areas that estimate consumers' willingness to pay for lower noise levels. Most of these studies are summarized in the key reference by Nelson (1982), which compiles the results of major highway noise studies and "normalizes the results into a noise depreciation sensitivity index (NDSI)."[40] Based on previous studies, Nelson[41] concluded that the average loss in residential property values was 0.4 percent for every decibel above the threshold level. Using the median housing value from the 1993 Census survey, annualized at a 10 percent discount rate and multiplied by the 0.4 percent, FHWA estimated a highway noise cost of about $35 per decibel per housing unit. [42]

Although housing residents may not react in exactly the same way to railroad noises, highway noise factors provide some insights as to potential changes in market valuations that might result from increased railroad noise. As Table 35 shows, residential property values vary considerably from rural to urban areas and within metropolitan regions. Moreover, a noise event in an urban area will affect more households than a noise event in a rural area. As a result, noise costs may vary with the type of residential areas adjacent to rail lines and the distribution of train-miles between rural and urban areas.

Table 35. 1993 Value of Housing Units in the United States

	Number of Units (thousands)	**Median Purchase Price ($)**	**Median Value ($)**
Urban – Outside Primary MSAs	4,800	30,988	58,650
Urban Total	40,667	49,633	93,098
Rural Suburbs	10,094	51,056	92,413
Rural – Outside Primary MSAs	10,370	29,463	58,410
Rural Total	20,585	37,593	73,407
Total Occupied Units	61,252	45,292	86,529

Source: Compiled by FHWA from Bureau of the Census, *1993 American Housing Survey*.

EPA Locomotive Noise Regulations

The railroad emission standards set by EPA are codified in 40 CFR Part 201. Although EPA sets noise standards, Federal Railroad Administration is responsible for testing, inspecting, and enforcing railroad noise regulations, as described in 49 CFR Part 210. It should be noted that the noise regulations discussed below do not apply to train horns.

EPA regulations vary somewhat with the manufacture date of the locomotive, the duty cycle, and whether the locomotive is stationary or in motion. A stationary locomotive manufactured on or before December 31, 1979 cannot produce A-weighted sound levels in excess of 93 dB at any throttle setting except idle when measured at a distance of 100 feet from the geometric center of the locomotive (Table 36). A stationary locomotive manufactured after December 31, 1979 cannot produce sound levels in excess of 87 dBA at any throttle setting except idle, when measured at the same distance. When in motion, a locomotive manufactured on or before December 31, 1979 cannot produce sound levels in excess of 96 dBA at 100 feet from the centerline of the track. Using the same measurement criteria, a locomotive manufactured after December 31, 1979 cannot produce A-weighted sound levels in excess of 90 dB when in motion.

Table 36. Locomotive Noise Regulations - Other than Switcher Units

Manufacture Date	Operation	Maximum dBA
On or Before 12/31/76	Stationary	93
	In-Motion	96
After 12/31/76	Stationary	87
	In-Motion	90

EPA regulations also govern freight car noise emissions. According to Section 201.13, a rail carrier cannot operate rail cars that produce sound levels (while in motion) in excess of 88 dBA at speeds up to and including 45 mph, or 93 dBA at car speeds greater than 45 mph, when measured at 100 feet from the centerline of the track. Given the regulatory maximums, it is likely that a freight train in motion produces noise levels of 88 to 96 dBA at distances of 100 feet from the track along a line source of several minutes duration. Moreover, it appears that a substantial increase in trains per day through a community has the potential for increasing existing noise levels in relation to the community impact thresholds discussed earlier.

Noise and Safety Impacts of Locomotive Horns

The locomotive horn or whistle is a very controversial community issue that has implications for both safety and noise levels. Horns provide an audible warning of approaching trains and indications of train speed, direction, and proximity. Although the acoustic characteristics of locomotive horns may vary somewhat, Table 37 shows representative sound levels (L_{max}) and durations for phases of a locomotive horn sounded during a highway grade crossing approach. Although the horn phases are considerably shorter in duration than a train passage, the maximum sound levels are greater. Like other train noises, horn noise is attenuated by distance and mitigated by intervening structures and land uses. Although there is no “average” noise level, the FRA horn noise model is based on an SEL of 107 dBA at 100 feet from the tracks for locations not closer than 1/8 mile from a grade crossing.[43] Many community complaints arise in regard to nighttime soundings of the horn when ambient noise levels are much lower than during the day.

Table 37. Sound Levels of Locomotive Horn from FRA/Volpe Test		
Horn Phase	**Max (dbA)**	**Duration (sec.)**
Long	114.6	5.00
Long	115.4	6.00
Short	111.9	2.75
Long	115.1	5.88
Source: USDOT, FRA. The Safety of Highway Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems, July, 1993.		

A number of communities across the nation have regulated or attempted to regulate the use of locomotive horns in their jurisdictions. Following the large-scale imposition of train whistle bans in Florida, FRA became aware of a strong relationship between the use of locomotive horns and collision rates at highway-rail crossings. In April 1995, FRA prepared a *Nationwide Study on Train Whistle Bans*. The study showed that "absent compensatory safety measures, whistle bans substantially increase the risk of deaths and injuries at highway-rail crossings." Congress directed FRA to issue a rule requiring the use of train horns at all public grade crossings. However, FRA was given authority to make "reasonable exceptions to the use of train horns" in certain circumstances. Pursuant to these laws and safety concerns, FRA prepared a Notice of Proposed Rulemaking (NPRM) to address the use of locomotive horns at public grade crossings. The agency now is faced with the difficult task of balancing safety needs against the impacts of horn noise on surrounding communities.

In preparation for the rulemaking, FRA developed a horn noise impact model. The results of the model suggest that approximately 365,000 additional persons could be impacted by horn noise as a result of eliminating community whistle bans at 1,978 highway-railroad grade crossings. Of this number, approximately 151,000 fall into the "severely impacted category." However, FRA notes that the proposed action could also benefit many people as a result of the proposed mitigation provisions.[44] Currently, the horn-sounding duration is one-quarter mile from a crossing. FRA is proposing a 20-second horn-sounding distance (under certain circumstances) and a potential reduction in maximum horn noise (L_{max}) to104 dBA. When combined with a proposed horn "directionality provision," FRA suggests that the proposed rules "could reduce community horn noise exposure by 60 percent on average" in communities that have not enacted whistle bans.

The FRA rule-making proceeding is very important to community noise levels and to comparisons among modes. If the rules are adopted and withstand potential court challenges, they have significant implications for the study region. The state of Illinois contains by far the greatest number of potentially impacted persons.[45] Nearly half (49 percent) of all persons potentially impacted by the elimination of whistle bans reside in the state of Illinois. Wisconsin and Minnesota rank third and fifth respectively in terms of potentially impacted populations. Because the rule-making proceeding is on-going, opportunities exist to develop potential noise impact factors from testimony and data presented by FRA, railroads, and communities. It is recommended that the proceeding be monitored and a detailed review of the EIS, model, and working papers be conducted in the future.

Review of Railway Noise Studies

Although many studies were reviewed for this report, they all focused on highway or high-speed rail operations. The exception was a recent Transportation Research Board publication that provides some rough estimates of the costs of noise pollution due to incremental rail traffic. The study cites the Nelson study mentioned earlier, suggesting that a one decibel increase in noise causes a .4 percent decrease in housing value. The TRB report then presents a case study of some of the social costs that can result from a shift of waterway traffic to rail.

In the case study, there is no attempt to model the increased exposure to noise caused by a shift to rail. Instead, an average cost per truckload equivalent mile is used. Rail noise costs per truckload equivalent mile in urban areas are estimated at $.065 for loaded and for unloaded miles. These translate to roughly $.23 per rail car mile for grain (assuming 3.5 trucks per rail car). For rural areas, the rail noise costs were assumed to be $0. In estimating waterway noise costs for the case study, the report assumed the cost to be $0.

The TRB study heavily qualifies its estimates of social impacts, stating that a literature search was the only methodology used to obtain values for social impacts. Nonetheless, the study shows that the noise impacts of a shift from waterway to rail could be significant if their were a large traffic increase in urban areas.

Conclusions Regarding Railway Noise Impacts

Most noise impact studies address highway, aircraft, or high-speed rail noise. It was not possible within the time frame of the study to estimate railway noise costs, and the literature review did not discover factors that could be used with confidence. However, a current rule-making proceeding offers new data and opportunities including a horn noise model developed by FRA. Because communities in Illinois, Wisconsin, and Minnesota would be impacted heavily by the elimination of train whistle bans, horn noise is an important issue in the study region.

In general, train noise may be an important modal impact factor. As noted earlier, the allowable noise emissions for locomotives and freight cars are in the 87-96 dBA range. Given these noise levels, a more detailed study is warranted. Therefore, it is recommended that the rule-making proceeding be monitored and a detailed review of the EIS, model, and working papers be conducted. In a separate but related proceeding, the STB's final decision in the environmental review of the proposed Dakota, Minnesota, and Eastern (DM&E) Railroad's proposal to expand its rail lines into the Powder River Basin in Wyoming and thus increase traffic levels on its existing lines, is expected later this year. The DM&E case encompasses some important issues related to community noise levels and should be part of a more detailed study. Finally, in order to quantify noise costs, a more detailed analysis of railroad routes, train schedules, community land uses, and potentially-affected population and housing locations is required.

10. RAILROAD ENVIRONMENTAL ANALYSIS THRESHOLDS

Under the National Environmental Policy Act (NEPA), the Energy Policy and Conservation Act, and related legislation the Surface Transportation Board must assure adequate consideration of environmental and energy factors in railroad regulatory decisions (49CFR1105). Pursuant to these laws, STB has established thresholds for evaluating whether potential changes in railroad traffic and operations might result in significant environmental impacts. The STB thresholds are related to potential rail system changes such as construction, abandonment, and merger. However, they describe incremental railroad traffic levels that might trigger an environmental analysis during a regulatory proceeding, and thus suggest areas where more detailed studies of potential environmental benefits might be warranted for future waterway investment studies.

In evaluating proposed rail system changes, STB must decide whether an environmental report is necessary and what level of detail is required. A proposed change may trigger the need for one of two types of environmental reports: an Environmental Impact Statement (EIS) or an Environmental Assessment (EA). An EIS is a detailed written statement required by NEPA for a major Federal action significantly affecting the quality of the human environment. An EA is a concise report that contains sufficient information for determining whether it is necessary to prepare an EIS or whether the Surface Transportation Board can make a finding of "no significant environmental impact. "

Normally, an EIS is required for a rail construction proposal involving new right-of-way. An EA normally is required for the following proposed actions: (1) construction of connecting track within existing rail rights-of-way or on land owned by the connecting railroads; (2) abandonment of a rail line; (3) discontinuance of passenger train or freight service; and (4) a consolidation, merger, acquisition, lease, or operating change that will result in incremental traffic levels exceeding any of the thresholds discussed below.

An environmental report to the STB must include an estimate of the amount of traffic that will be diverted to other transportation systems or modes as a result of the proposed action. If certain thresholds are met or exceeded, the report must also include a description of energy, air quality, and noise impacts. These environmental analysis thresholds are discussed below. In addition, the air quality and noise thresholds are summarized in Table 38.

Energy Threshold Criteria. [46] If the proposed action will cause diversions from rail to truck of more than 1,000 rail carloads a year or an average of 50 rail carloads per mile per year for any part of the affected line, the report must quantify the resulting net change in energy consumption and show the data and methodology used to arrive at the figure.

Emission Threshold Criteria (Other Than Nonattainment Areas).[47] The report must quantify the anticipated effect on air emissions if the proposed action will result in: (a) an increase in rail traffic of at least 100 percent (measured in gross ton miles annually) or an increase of at least eight trains a day on any segment of rail line affected by the proposal, (b) an increase in rail yard activity of at least 100 percent (measured by carload activity), or (c) an average increase in truck traffic of more than 10 percent of the average daily traffic or 50 vehicles a day on any affected road segment.

Emission Threshold Criteria (Nonattainment Areas).[48] If the proposed action affects a class I or nonattainment area under the Clean Air Act, and will result in either: (a) an increase in rail traffic of at least 50 percent (measured in gross ton miles annually) or an increase of at least three trains a day on any segment of rail line, (b) an increase in rail yard activity of at least 20 percent (measured by carload activity), or (c) an average increase in truck traffic of more than 10 percent of the average daily traffic or 50 vehicles a day on a given road segment, then the report must state whether any expected increased emissions are within the parameters established by the State Implementation Plan.

Noise Threshold Criteria.[49] The environmental report must quantify the anticipated effect on noise if the proposed action will result in: (a) an increase in rail traffic of at least 100 percent (measured in gross ton miles annually) or an increase of at least eight trains a day on any segment of rail line affected by the proposal, (b) an increase in rail yard activity of at least 100 percent (measured by carload activity), or (c) an average increase in truck traffic of more than 10 percent of the average daily traffic or 50 vehicles a day on any affected road segment. Specifically, the report must state whether the proposed action will cause: (i) an incremental increase in noise levels of three decibels Ldn or more; or (ii) an increase to a noise level of 65 decibels Ldn or greater. If so, the report must identify sensitive receptors (e.g., schools, libraries, hospitals, residences, retirement communities, and nursing homes) in the project area, and quantify the noise increase for these receptors if the thresholds are surpassed.

11. CONCLUSION

Hopefully, this study has provided useful information to the USACE. Because of the high level of data aggregation and the short time frame, the results should be viewed as general findings. As the report suggests, railroads have become much more fuel efficient over time and the relative energy benefits of waterway transportation have become smaller. However, the analysis shows that there is a relatively small fuel advantage to barge transportation in this instance. This fuel efficiency advantage translates into lower emissions for the incremental traffic in the with-project scenario. However, the dollar benefits are not large assuming that railroads internalize the cost — in which case, the emission cost is equivalent to a compliance cost. However, if the railroads don't internalize the emission cost, a larger cost to society will result from pollution damage to health, property, and vegetation. Without further analysis and discussion with the Corps, the proportion or percentage of emission cost that isn't reflected in the NED calculations (if any) cannot be ascertained.

The study did not address potential impacts on non-attainment areas, where even a relatively modest increase in emissions could have significant impacts. In general, more research is needed to firm-up the emission, safety, and noise impacts. The accident approach used in this study could be improved by: (1) estimating a statistical model of railroad accidents instead of using average accident rates; (2) estimating accident probabilities for grade crossings, based on both rail and highway traffic exposure and crossing characteristics; and (3) looking at hazmat issues such as risk assessment and the broader implications of a hazmat grade crossing accident. As the report states, railroads are not necessarily to blame in many accident cases. Nevertheless, incremental railroad traffic may result in costs that are not borne by or internalized by the carrier. For example, it has been projected that traffic on the DM&E could increase from 3 trains per day to 37 trains per day within the next ten years. The Minnesota Department of Transportation is considering several options to enhance grade-crossing safety, including rebuilding grade crossing approaches, keeping vegetation under control, installing street lights at grade crossing approaches, introducing grade separations, closing some grade crossings, and other measures.[50]

As noted earlier, changes in noise levels may result from increased rail traffic. However the impacts will depend on the routes traveled, the population exposed to noise on the routes, and existing noise levels. Many communities in Illinois, Wisconsin, and Minnesota would be impacted heavily by the proposed elimination of train whistle bans. In general, train noise is an important issue in the study region and warrants more study. With more specific traffic and route data, it may be possible to forecast instances when the STB threshold criteria are reached. In conclusion, a follow-up study with a longer time frame may add valuable information.

Table 38 - STB THRESHOLDS FOR ENVIRONMENTAL ANALYSIS

Activity/Site	**Noise**	**Air Quality** **Attainment and Maintenance Areas**	**Air Quality** **Nonattainment Areas**
Rail Line Segments	Increase of 8 trains per day or increase of 100 percent in annual gross ton-miles.		Increase of 3 trains per day or increase of 50 percent in annual gross ton-miles.
Rail Yards	Increase of 100 percent in carload activity per day.		Increase of 20 percent in carload activity per day.
Intermodal Facilities	Increase of 50 trucks per day or increase of 10 percent in average daily traffic volume on any affected road segment.		
Source: Surface Transportation Board Authority: 49 CFR 1105.7(e)			

APPENDIX A. STATISTICAL DESCRIPTION OF RAILROAD FUEL USE MODELS

The purpose of this appendix is to review detailed statistical results and issues. Two issues frequently arise when evaluating statistical models: heteroskedasticity (non-constant variance) and serial correlation (autocorrelation). Heteroskedasticity is not an issue for the models formulated in this study. However, preliminary analysis indicated that serial correlation may exist within the data set.

Serial correlation is encountered most often when using time series or pooled data. A major assumption of the linear regression model is that any value of the dependent variable is statistically independent of any other value of the dependent variable. Stated another way, the error terms of the model are assumed to be statistically independent. This means that the error terms for any given railroad are not statistically correlated over time, and the model error terms are not statistically correlated across railroads. Even when autocorrelation exists, the parameter estimates are unbiased. However, the standard errors of the estimates are biased. Therefore, hypothesis tests may not turn out as expected.

The Durbin-Watson test is widely used to evaluate the existence and severity of autocorrelation. The Durbin-Watson (DW) statistic is computed from the residuals of a least-squares regression. The range of the DW statistic is zero-to-four. When it is close to 2.0, little or no autocorrelation exists. The farther the DW statistic lies from 2.0, the less confidence one has in the null hypothesis: that no autocorrelation exists.

A SAS procedure —Autoreg—corrects for serial correlation. In essence, the procedure incorporates the residuals from previous observations into the regression model for the current observation. In autoregression, the error term is assumed to be generated by an autoregressive process with a lag or order of *n*. If n equals 2, the error term in time period 3 (e.g., year 3) is assumed to be affected by the error terms in periods 1 and 2. When n = 1, first-order autocorrelation is said to exist. The Durbin-Watson statistic checks for first-order autocorrelation only. However, the SAS Autoreg procedure checks for higher orders of autocorrelation and determines how many autoregressive terms should be added to a model. These statistics are shown later for models 1 and 2.

Figure A.1 illustrates the relationship between gross ton-miles and fuel use discussed in the main report, while Figures A.2 and A.3 provide details of the corrected models. Several statistical tests were used to check for non-constant variance. For all tests, the null hypothesis is constant variance (homoskedasticity). The p-values of the test statistics suggest that the null hypothesis should not be rejected. For example, the p-value of .75 for White's test for Model 2 suggests no evidence of non-constant variance in the uncorrected model. The SAS Autoreg procedure also tests for autoregressive conditional heteroskedasticity (ARCH). This test is specifically designed for time-series data. It checks for changes in variance across time using lag windows. As shown in Figures A.2 and A.3, the p-values for these tests suggest no autoregressive conditional heteroskedasticity.

```
Figure A.1 Graph of Railroad Fuel Use Against Thousand GTMC

                   Plot of FUELGAL*GTMC.  Legend: A = 1 obs, B = 2 obs, etc.

          FUELGAL ,
       1400000000 ˆ
                  ,
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                  ,
                  ,
                  ,                                                          A
       1200000000 ˆ
                  ,                                                        AA
                  ,
                  ,                                                    A
                  ,                                             A
                  ,
       1000000000 ˆ
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                  ,
                  ,
                  ,
                  ,
        800000000 ˆ                                         A
                  ,
                  ,                                       A
                  ,
                  ,                                  A
                  ,                               B
        600000000 ˆ                            BB
                  ,                         AAAC
                  ,
                  ,
                  ,
                  ,                  AABA BA
        400000000 ˆ               CA   AA
                  ,              AA  B   AA
                  ,            AAA  BA  A
                  ,            B BDB
                  ,             BBC
                  ,             A
        200000000 ˆ
                  ,
```

Figure A.2 Estimates of Model and Autoregressive Parameters for Model of Fuel Gallons as a Function of Unit Train GTMC, Through Train GTMC, and Way Train GTMC

Model Estimates (for Yule-Walker Method)

Reg Rsq	0.9977	Total Rsq	0.9972
Durbin-Watson	2.0926	PROB<DW	0.1917
SSE	2.272E16	DFE	89
MSE	2.553E14	Root MSE	15978785
Dep. Variable Mean:			294943720
Coefficient of Variation:			5.4

Variable	DF	Parameter Estimate	Std. Error	t Ratio	Prob. of >|t|
Intercept	1	22630565	6342472	3.568	0.0006
UTGTM	1	0.702475	0.1260	5.574	0.0001
TTGTM	1	0.859628	0.1057	8.135	0.0001
WTGTM	1	2.212445	0.8959	2.470	0.0154
BNSF	1	48309287	20068348	2.407	0.0181
ATSF	1	164047501	19013071	8.628	0.0001
BN	1	252906254	38380858	6.589	0.0001
UPSP	1	34309403	22107097	1.552	0.1242
UPCNW	1	7020651	22463351	0.313	0.7554
SP	1	174285955	20327262	8.574	0.0001
UP	1	232620528	34927716	6.660	0.0001
CNW	1	8180228	8475702	0.965	0.3371
KCS	1	141479	6663893	0.021	0.9831
SOO	1	-8470059	7451005	-1.137	0.2587
CR	1	80218472	19321542	4.152	0.0001
CSX	1	118121455	27615354	4.277	0.0001
GTW	1	-5450163	6922073	-0.787	0.4332
NS	1	103449913	22984636	4.501	0.0001
T	1	-611776	860547	-0.711	0.4790

Estimates of the Autoregressive Parameters

Lag	Coefficient	Std Error	t Ratio
1	-0.30826922	0.099444	-3.100
2	0.22844714	0.096893	2.358
4	0.33327920	0.094762	3.517

Figure A.3 Estimates of Model and Autoregressive Parameters for Model Results and Parameter Estimates of Model 2:

Log of Revenue Ton-Miles per Gallon As a Function of the Log of Rev. Tons per Train (LREV), Log of Tare Tons per Train (LTARE), Log of Average Length of Haul (LALH), Railroad Indicator Variables, and Time

Yule-Walker Estimates

Reg Rsq	0.9406	Total Rsq	0.9439
SSE	0.230282	DFE	89
MSE	0.002587	Root MSE	0.050867
Durbin-Watson	1.9001	PROB<DW	0.0295

Variable	DF	B Value	Std Error	t Ratio	Approx Prob
Intercept	1	2.883718	0.8473	3.403	0.0010
LREVTON	1	0.419565	0.1140	3.680	0.0004
LTARE	1	-0.330859	0.1130	-2.927	0.0043
LALH	1	0.374356	0.0759	4.933	0.0001
BNSF	1	0.478300	0.0985	4.854	0.0001
ATSF	1	-0.566800	0.0929	-6.100	0.0001
BN	1	-0.301441	0.0700	-4.309	0.0001
UPSP	1	0.425177	0.0980	4.340	0.0001
UPCNW	1	-0.185472	0.0639	-2.903	0.0047
SP	1	-0.518807	0.0834	-6.222	0.0001
UP	1	-0.344101	0.0825	-4.169	0.0001
CNW	1	0.211314	0.0377	5.609	0.0001
KCS	1	-0.101502	0.0245	-4.150	0.0001
SOO	1	0.022080	0.0303	0.729	0.4677
CR	1	-0.124029	0.0531	-2.335	0.0218
CSX	1	-0.082535	0.0459	-1.800	0.0753
GTW	1	-0.219896	0.0753	-2.920	0.0044
NS	1	-0.135665	0.0377	-3.600	0.0005
T	1	0.019500	0.00246	7.930	0.0001

Q and LM Tests for ARCH Disturbances

Order	Q	Prob>Q	LM	Prob>LM
1	1.2353	0.2664	1.1898	0.2754
2	1.5467	0.4615	1.6365	0.4412
3	1.6829	0.6407	1.6907	0.6390
4	1.9782	0.7398	1.9839	0.7387
5	8.1482	0.1483	7.1254	0.2115
6	8.4305	0.2082	8.0958	0.2312

APPENDIX B. ANALYSIS OF MODEL PREDICTION ERRORS AND ESTIMATES OF REVENUE TON MILES PER GALLON FOR HYPOTHETICAL TRAIN MOVEMENTS

Appendix B: Table B.1
Predictions and Errors of Fuel Regression Model 1:
Fuel Gallons As a Function of GTMC Variables

-- Railroad=BN --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	203	379	422	-2.65
1990	199	375	418	-1.05
1991	201	376	419	3.08
1992	202	379	421	3.33
1993	202	381	425	-0.26
1994	209	401	449	-3.75
1995	218	425	479	-6.29
1996	210	390	433	-5.49
1997	195	371	415	0.83
1998	200	389	437	-0.14

-- Railroad=CR --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	182	319	381	-5.12
1990	192	325	381	-1.35
1991	184	326	399	4.16
1992	182	329	405	2.06
1993	176	335	381	-0.26
1994	176	347	404	-4.83
1995	180	346	429	1.06
1996	183	350	426	-0.76
1997	180	357	424	-0.81
1998	185	364	439	-0.88

Appendix B: Table B.1

Predictions and Errors of Fuel Regression Model 1:

Fuel Gallons As a Function of GTMC Variables

-- Railroad=CSX --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	200	395	446	-18.95
1990	189	381	432	-9.70
1991	196	389	439	-6.88
1992	191	384	435	-4.10
1993	184	372	422	10.96
1994	188	383	435	7.50
1995	191	390	445	6.81
1996	187	384	437	-7.76
1997	192	396	452	-7.20
1998	188	391	446	-6.09

-- Railroad=GTW --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	150	183	195	-0.65
1990	125	181	214	0.15
1991	123	187	184	9.42
1992	128	202	195	8.10
1993	138	229	223	-2.96
1994	138	240	219	0.82
1995	126	253	242	-1.66
1996	165	308	262	0.14
1997	158	310	360	-8.66
1998	156	317	360	-0.80

Appendix B: Table B.1

Predictions and Errors of Fuel Regression Model 1:

Fuel Gallons As a Function of GTMC Variables

-- Railroad=ICG --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	184	338	354	-7.73
1990	198	345	374	0.96
1991	205	379	405	-2.91
1992	208	378	411	-0.40
1993	214	399	411	2.85
1994	215	409	449	-2.07
1995	222	436	474	-3.96
1996	218	424	462	-1.23
1997	216	431	467	-2.25
1998	220	440	484	-1.68

-- Railroad=KCS --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	179	279	296	15.90
1990	180	292	292	19.10
1991	182	299	305	23.05
1992	188	319	327	21.07
1993	192	333	339	16.92
1994	186	336	344	-4.54
1995	205	388	407	-15.05
1996	200	385	395	-12.28
1997	210	405	436	-17.69
1998	217	432	451	-23.05

Appendix B: Table B.1

Predictions and Errors of Fuel Regression Model 1:

Fuel Gallons As a Function of GTMC Variables

-- Railroad=NS --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	206	336	374	-5.10
1990	205	355	445	-2.29
1991	208	347	396	3.54
1992	211	349	407	2.68
1993	213	358	420	1.97
1994	218	377	436	-2.14
1995	217	385	443	-0.31
1996	217	387	446	-1.51
1997	221	398	459	-2.07
1998	215	392	446	-5.42

-- Railroad=SOO --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	239	446	515	-4.94
1990	235	475	544	-4.48
1991	235	477	563	-3.58
1992	235	488	572	-4.83
1993	241	489	592	-5.33
1994	249	460	541	-8.16
1995	253	488	595	-14.60
1996	253	496	613	-23.58
1997	257	493	586	-16.02
1998	256	487	542	-11.88

Appendix B: Table B.1
Predictions and Errors of Fuel Regression Model 1:
Fuel Gallons As a Function of GTMC Variables

-- Railroad=UP --

Year	Predicted RTM per Gallon Way Train	Predicted RTM per Gallon Through Train	Predicted RTM per Gallon Unit Train	Prediction Error As Percent
1989	177	328	364	-1.43
1990	178	333	371	-3.39
1991	183	346	386	0.81
1992	186	353	394	1.66
1993	188	362	405	-1.30
1994	190	371	417	-1.70
1995	201	406	460	-0.86
1996	203	414	470	-8.28
1997	191	374	421	-4.43
1998	188	365	410	-0.34

Appendix B: Table B.2
Prediction Errors of Model 2: Log of Revenue Ton-Miles per Gallon
As a Function of the Logs of Revenue Tons, Tare Tons, and Avg. Distance

-- Railroad=BN --

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	388	393	-1.207
1990	383	396	-3.260
1991	395	414	-4.671
1992	403	416	-3.052
1993	412	404	2.094
1994	429	413	3.928
1995	455	431	5.560
1996	416	385	8.163
1997	383	389	-1.389
1998	405	406	-0.397

Appendix B: Table B.2

Prediction Errors of Model 2: Log of Revenue Ton-Miles per Gallon

As a Function of the Logs of Revenue Tons, Tare Tons, and Avg. Distance

-- Railroad=CR --

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	311	301	3.254
1990	318	318	-0.010
1991	327	338	-3.318
1992	329	333	-1.190
1993	327	330	-0.882
1994	335	327	2.592
1995	346	347	-0.245
1996	352	344	2.367
1997	357	350	1.768
1998	365	358	2.092

-- Railroad=CSX --

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	361	332	8.836
1990	346	347	-0.196
1991	369	363	1.723
1992	373	366	1.904
1993	373	416	-10.265
1994	374	420	-10.877
1995	387	428	-9.759
1996	387	366	5.898
1997	401	379	5.691
1998	403	378	6.552

Appendix B: Table B.2

Prediction Errors of Model 2: Log of Revenue Ton-Miles per Gallon

As a Function of the Logs of Revenue Tons, Tare Tons, and Avg. Distance

-- Railroad=GTW --

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	186	181	2.847
1990	185	182	1.946
1991	204	204	-0.112
1992	219	217	1.242
1993	231	220	5.014
1994	233	238	-2.004
1995	255	245	4.141
1996	285	303	-5.929
1997	282	288	-1.975
1998	293	317	-7.622

-- Railroad=ICG --

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	333	303	9.741
1990	348	342	1.868
1991	370	362	2.216
1992	377	372	1.392
1993	397	398	-0.289
1994	397	403	-1.597
1995	428	427	0.390
1996	420	423	-0.734
1997	425	425	0.048
1998	434	441	-1.635

Appendix B: Table B.2

Prediction Errors of Model 2: Log of Revenue Ton-Miles per Gallon

As a Function of the Logs of Revenue Tons, Tare Tons, and Avg. Distance

-- Railroad=KCS --

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	338	335	0.920
1990	341	355	-3.999
1991	344	385	-10.725
1992	354	401	-11.557
1993	357	396	-9.736
1994	320	311	2.876
1995	352	329	7.177
1996	351	329	6.537
1997	375	335	12.102
1998	383	341	12.149

-- Railroad=NS --

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	320	317	1.047
1990	341	349	-2.220
1991	344	357	-3.608
1992	349	356	-2.108
1993	358	363	-1.121
1994	368	368	0.035
1995	375	382	-1.795
1996	380	379	0.297
1997	390	387	0.853
1998	382	368	3.610

Appendix B: Table B.2

Prediction Errors of Model 2: Log of Revenue Ton-Miles per Gallon

As a Function of the Logs of Revenue Tons, Tare Tons, and Avg. Distance

Railroad=SOO

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	380	375	1.168
1990	393	400	-1.934
1991	401	418	-4.191
1992	405	428	-5.352
1993	414	436	-5.174
1994	408	412	-1.012
1995	441	433	1.782
1996	458	408	12.397
1997	481	433	11.162
1998	446	438	1.841

Railroad=UP

Year	Predicted Rev. Ton-Miles per Gallon	Actual Rev. Ton-Miles per Gallon	Predict. Error As Percent Of Actual
1989	334	330	1.140
1990	339	329	3.171
1991	347	358	-3.031
1992	354	368	-3.766
1993	363	368	-1.433
1994	372	375	-0.837
1995	401	415	-3.446
1996	413	397	4.088
1997	374	370	1.079
1998	386	376	2.773

Appendix B: Table B.3

Predicted Revenue Ton-Miles per Gallon for Select Train Weights and Distances

Summary by Railroad

-- Railroad=BN --

Train Type	Trip Distance	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
Mixed_Way	150	20	75	195
Grain_Way	150	25	100	224
TOFC_Thru	400	75	30	237
Mixed_Thru	400	75	75	316
Grain_Thru	400	75	100	356
TOFC_Thru	800	75	30	307
Mixed_Thru	800	75	75	409
Grain_Thru	800	75	100	462

-- Railroad=CR --

Train Type	Trip Distance	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
Mixed_Way	150	20	75	254
Grain_Way	150	25	100	292
TOFC_Thru	400	75	30	309
Mixed_Thru	400	75	75	412
Grain_Thru	400	75	100	465
TOFC_Thru	800	75	30	400
Mixed_Thru	800	75	75	534
Grain_Thru	800	75	100	603

-- Railroad=ICG --

Train Type	Trip Distance	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
Mixed_Way	150	20	75	287
Grain_Way	150	25	100	331
TOFC_Thru	400	75	30	349
Mixed_Thru	400	75	75	467
Grain_Thru	400	75	100	526
TOFC_Thru	800	75	30	453
Mixed_Thru	800	75	75	605
Grain_Thru	800	75	100	682

Appendix B: Table B.3

Predicted Revenue Ton-Miles per Gallon for Select Train Weights and Distances

Summary by Railroad

-- Railroad=NS --

Train Type	Trip Distance	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
Mixed_Way	150	20	75	251
Grain_Way	150	25	100	289
TOFC_Thru	400	75	30	305
Mixed_Thru	400	75	75	407
Grain_Thru	400	75	100	460
TOFC_Thru	800	75	30	395
Mixed_Thru	800	75	75	528
Grain_Thru	800	75	100	596

-- Railroad=UP --

Train Type	Trip Distance	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
Mixed_Way	150	20	75	190
Grain_Way	150	25	100	219
TOFC_Thru	400	75	30	231
Mixed_Thru	400	75	75	309
Grain_Thru	400	75	100	349
TOFC_Thru	800	75	30	300
Mixed_Thru	800	75	75	401
Grain_Thru	800	75	100	452

Appendix B: Table B.3

Predicted Revenue Ton-Miles per Gallon for Select Train Weights and Distances

Summary by Train Type

----------------------------------- Train Type=Grain_Thru ------------------------------------

Trip Distance	Railroad	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
400	UP	75	100	349
400	BN	75	100	356
400	NS	75	100	460
400	CR	75	100	465
400	ICG	75	100	526
800	UP	75	100	452
800	BN	75	100	462
800	NS	75	100	596
800	CR	75	100	603
800	ICG	75	100	682

------------------------------------ Train Type=Grain_Way ------------------------------------

Trip Distance	Railroad	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
150	UP	25	100	219
150	BN	25	100	224
150	NS	25	100	289
150	CR	25	100	292
150	ICG	25	100	331

Appendix B: Table B.3

Predicted Revenue Ton-Miles per Gallon for Select Train Weights and Distances

Summary by Train Type

------------------------------------ Train Type=Mixed_Thru ------------------------------------

Trip Distance	Railroad	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
400	UP	75	75	309
400	BN	75	75	316
400	NS	75	75	407
400	CR	75	75	412
400	ICG	75	75	467
800	UP	75	75	401
800	BN	75	75	409
800	NS	75	75	528
800	CR	75	75	534
800	ICG	75	75	605

------------------------------------ Train Type=Mixed_Way ------------------------------------

Trip Distance	Railroad	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
150	UP	20	75	190
150	BN	20	75	195
150	NS	20	75	251
150	CR	20	75	254
150	ICG	20	75	287

------------------------------------ Train Type=TOFC_Thru ------------------------------------

Trip Distance	Railroad	Cars Per Train	Tons Per Car	Predicted Rev. Ton-Miles per Gallon
400	UP	75	30	231
400	BN	75	30	237
400	NS	75	30	305
400	CR	75	30	309
400	ICG	75	30	349
800	UP	75	30	300
800	BN	75	30	307
800	NS	75	30	395
800	CR	75	30	400
800	ICG	75	30	453

APPENDIX C. SUMMARY OF 1998 RAILROAD SHIPMENT CHARACTERISTICS FOR FARM PRODUCT TRAFFIC ORIGINATING IN BUSINESS ECONOMIC ANALYSIS AREAS ADJACENT TO UPPER MISSIPPI RIVER-ILLINOIS WATERWAY SYSTEM

Table C.1 Characteristics of Farm Products Shipments Originating by Rail in Illinois River BEAs-1998

Destination	Shipment Size	Percent of Tons	Avg. Cars per Shipment
Eastern U.S.	3 to 15 Cars	33.41%	10
Eastern U.S.	16 to 60 Cars	30.93%	30
Eastern U.S.	61 to 100 Cars	21.40%	65
Eastern U.S.	1 to 2 Cars	14.26%	1
Gulf - Mississippi	61 to 100 Cars	52.10%	98
Gulf - Mississippi	16 to 60 Cars	40.68%	33
Gulf - Mississippi	3 to 15 Cars	4.99%	11
Gulf - Mississippi	Over 100 Cars	2.23%	101
Gulf - Texas	16 to 60 Cars	42.78%	24
Gulf - Texas	61 to 100 Cars	35.51%	75
Gulf - Texas	3 to 15 Cars	21.71%	8
Illinois	16 to 60 Cars	80.41%	38
Illinois	3 to 15 Cars	17.22%	8
Illinois	61 to 100 Cars	1.29%	66
Illinois	1 to 2 Cars	1.07%	1
Lower Mississippi Valley	16 to 60 Cars	80.99%	26
Lower Mississippi Valley	3 to 15 Cars	13.79%	7
Lower Mississippi Valley	61 to 100 Cars	4.65%	73
Lower Mississippi Valley	1 to 2 Cars	0.58%	1
Missouri	16 to 60 Cars	71.01%	30
Missouri	3 to 15 Cars	15.78%	6
Missouri	61 to 100 Cars	12.40%	98
Missouri	1 to 2 Cars	0.81%	1
Pacific Northwest	1 to 2 Cars	99.99%	1
Western U.S.	61 to 100 Cars	93.49%	78
Western U.S.	1 to 2 Cars	4.51%	2
Western U.S.	3 to 15 Cars	2.00%	3

Table C.2 Characteristics of Railroad Farm Products Shipments Originating from Iowa BEAs- 1998			
Destination	**Shipment Size**	**Percent of Tons**	**Avg. Cars per Shipment**
California	61 to 100 Cars	61.38%	78
California	16 to 60 Cars	38.62%	53
Eastern U.S.	16 to 60 Cars	100.00%	38
Gulf - Mississippi	16 to 60 Cars	87.61%	40
Gulf - Mississippi	61 to 100 Cars	12.39%	87
Gulf - Texas	16 to 60 Cars	68.83%	31
Gulf - Texas	61 to 100 Cars	31.17%	74
Illinois	61 to 100 Cars	56.29%	76
Illinois	16 to 60 Cars	41.82%	35
Illinois	3 to 15 Cars	1.01%	11
Illinois	Over 100 Cars	0.80%	108
Illinois	1 to 2 Cars	0.08%	1
Lower Mississippi Valley	16 to 60 Cars	71.85%	29
Lower Mississippi Valley	61 to 100 Cars	24.77%	74
Lower Mississippi Valley	3 to 15 Cars	3.38%	5
Missouri	16 to 60 Cars	97.26%	33
Missouri	3 to 15 Cars	2.06%	10
Missouri	1 to 2 Cars	0.68%	1
Pacific Northwest	61 to 100 Cars	50.90%	100
Pacific Northwest	Over 100 Cars	27.50%	107
Pacific Northwest	16 to 60 Cars	21.60%	50
Western U.S.	16 to 60 Cars	61.46%	36
Western U.S.	61 to 100 Cars	21.64%	76
Western U.S.	Over 100 Cars	9.81%	105
Western U.S.	3 to 15 Cars	7.09%	7

Table C.3 Characteristics of Railroad Farm Products Shipments Originating from MN BEAs- 1998

Destination	Shipment Size	Percent of Tons	Avg. Cars Per Shipment
California	61 to 100 Cars	78.72%	74
California	16 to 60 Cars	21.28%	46
Eastern U.S.	3 to 15 Cars	100.00%	4
Gulf - Mississippi	61 to 100 Cars	85.92%	85
Gulf - Mississippi	16 to 60 Cars	14.09%	24
Gulf - Texas	61 to 100 Cars	65.62%	83
Gulf - Texas	Over 100 Cars	34.38%	104
Illinois	16 to 60 Cars	68.29%	27
Illinois	1 to 2 Cars	15.51%	1
Illinois	61 to 100 Cars	14.07%	74
Illinois	3 to 15 Cars	2.12%	6
Iowa	3 to 15 Cars	55.04%	8
Iowa	16 to 60 Cars	44.97%	30
Lower Mississippi Valley	16 to 60 Cars	100.00%	27
Minnesota	16 to 60 Cars	46.11%	32
Minnesota	1 to 2 Cars	33.70%	1
Minnesota	3 to 15 Cars	20.19%	6
Missouri	16 to 60 Cars	55.21%	34
Missouri	1 to 2 Cars	21.66%	1
Missouri	Over 100 Cars	13.72%	106
Missouri	61 to 100 Cars	7.46%	77
Missouri	3 to 15 Cars	1.95%	5
Pacific Northwest	Over 100 Cars	64.34%	108
Pacific Northwest	61 to 100 Cars	19.17%	97
Pacific Northwest	16 to 60 Cars	11.38%	35
Pacific Northwest	1 to 2 Cars	3.21%	1
Pacific Northwest	3 to 15 Cars	1.91%	4
Western U.S.	61 to 100 Cars	72.03%	75
Western U.S.	16 to 60 Cars	20.14%	25
Western U.S.	1 to 2 Cars	3.98%	1
Western U.S.	3 to 15 Cars	3.85%	3
Wisconsin	1 to 2 Cars	39.81%	1
Wisconsin	3 to 15 Cars	33.52%	8
Wisconsin	16 to 60 Cars	26.67%	23

Table C.4 Characteristics of Railroad Farm Products Shipments Originating from MO BEAs- 1998			
Destination	**Shipment Size**	**Percent of Tons**	**Avg. Cars per Shipment**
Eastern U.S.	3 to 15 Cars	84.11%	12
Eastern U.S.	16 to 60 Cars	15.89%	24
Gulf - Mississippi	3 to 15 Cars	100.01%	3
Gulf - Texas	3 to 15 Cars	100.00%	7
Illinois	16 to 60 Cars	44.81%	51
Illinois	3 to 15 Cars	37.19%	4
Illinois	1 to 2 Cars	18.00%	2
Lower Mississippi Valley	3 to 15 Cars	59.01%	5
Lower Mississippi Valley	16 to 60 Cars	40.99%	25
Missouri	3 to 15 Cars	78.57%	8
Missouri	1 to 2 Cars	11.45%	1
Missouri	16 to 60 Cars	9.97%	20
Western U.S.	3 to 15 Cars	100.00%	4

Table C.5 Characteristics of Railroad Farm Products Shipments Originating from MO BEAs- 1998			
Destination	**Shipment Size**	**Percent of Tons**	**Avg. Cars per Shipment**
Illinois	16 to 60 Cars	90.40%	29
Illinois	3 to 15 Cars	7.04%	5
Illinois	1 to 2 Cars	2.56%	1
Missouri	16 to 60 Cars	100.00%	25

Appendix D
Reviewers' Comments and Author's Responses

Preface. *USACE contracted with Tennessee Valley Authority to review this report. Appendix D contains the comments of TVA and Dr. Mark Burton of Marshall University. My responses are shown in italicized text, following the reviewers' comments. Two exhibits developed by the reviewers are not in word-processing format and therefore, are not included in this appendix. However, they can be obtained from the USACE.*

Dr. Denver Tolliver was asked by the Rock Island District of the U. S. Army Corps of Engineers to investigate the environmental benefits of the project alternatives being investigated for construction on the Upper Mississippi and Illinois Waterways. The Tennessee Valley Authority (TVA) was asked to do an independent technical review (ITR) of Dr. Tolliver's report. TVA asked Dr. Mark Burton at Marshall University to assist with the review. In summary, the reviewers feel that a reasonably defensible assessment of fuel, emissions, pollution abatement and safety differentials was prepared for the various "with" and "without" project conditions. But with the "devil" being in the details, the reviewers do have some questions and comments about methodology and assumptions used in the study, especially as they relate to suspected impacts on study conclusions.

A Short History

The analysis of the environmental impacts of intermodal shifts began with the work of Bill Newstrand at the Minnesota Department of Transportation in the early 1990's and has been expanded by TVA, Marshall University, and others. From Mr. Newstrand's simple ratios of incidents or consumption per ton or ton-mile, the work has become extremely data-intensive and has changed rapidly from one project to another as new and improved data and techniques (the application of Geographic Information Systems for example) have become available for use. TVA completed a study of environmental impacts related to transportation on the upper Mississippi River and Illinois Waterways in the middle 1990's, but the study did not identify impacts related to any specific alternative, which, of course, did not exist at that time. Dr. Tolliver's study does utilize TVA's estimates of towboat efficiency for the upper Mississippi River and Illinois Waterways. TVA's comments on the report follow below.

Strong Points

A fairly common reaction among those who have read the paper is that it is easy to read. This is because the study is well written and thus provides an easily understood general framework of analysis. A particular strong point of the paper is an insightful analysis of modal energy efficiency. This is an excellent paper for those who have not studied in the area, and TVA has recommended the paper to the Institute for Water Resources (IWR) as a source of discussion regarding the issue of modern railroad diesel engine efficiency in comparison to the current industry average. Dr. Tolliver does an interesting and effective discussion of this issue which is particularly effective given the current work of Dr. Philip Baumel regarding the energy efficiency of modern unit trains as compared to existing industry average towboat efficiency.

Our hat is off to Dr. Tolliver's use of the STB's R-1 data in the estimation of railroad fuel consumption. We are a bit jealous that we didn't think of it. In any case, we believe that the methodology developed within this study is robust and defensible.

The discussion of safety impacts is sound and provides useful results. The approach used to estimate accidents has been improved and can easily be used in other applications.

Points of Concern

When working in the area of environmental impacts of intermodal traffic shifts, we at TVA and Marshall University have attempted to push forward the frontier of knowledge with each project. This is a relatively new area of study which results in our analytical framework changing to a degree in response, first, to our gaining a better understanding of the subject matter from project to project. However, we have also gained from critical review and resource availability. Dr. Tolliver's work for the Rock Island District is reflective of our upper Mississippi River efforts undertaken in the mid-1990's and does not incorporate our more recent studies, although his thoughts for potential future improvements seem to track what we are already implementing. To a degree, this is a reflection of the limited time and money that was dedicated to his project.

Approach and Key Assumptions

Dr. Tolliver uses two approaches to assess air quality impacts. In the first approach it is assumed that the railroads will keep emissions at the same level in the with-project and without-project scenarios, and in so doing will incur a compliance or abatement cost. In the second approach, if the incremental emissions are not abated or offset by reductions elsewhere, then overall emissions from overland sources will increase and there will be a cost to society that is not internalized. In this case, it is argued that incremental emissions of nitrogen oxides, particulate matter, and other pollutants will adversely impact human health, property values, vegetation and crop values. Whichever approach is used, the study shows a disparate value of the waterway that would be attributed to air quality. In the first approach, scenario "J" air pollution benefits attributable to barge transportation contribute only 0.87% of the total benefit stream (internalizing cost) while approach two yields 20.9% of total benefits (cost not being internalized).

We feel that the first approach, that the railroads will internalize pollution abatement cost, needs additional work and some justification if Dr. Tolliver really feels strongly about this idea. Our thoughts on this matter are as follows. Cost-based pricing was abandoned with passage of the Rail Staggers Act which allows railroads to exercise demand-based pricing. Thus, we feel that the railroads would be unlikely to absorb the whole of any pollution abatement costs and, instead, would increase rates, when possible, to cover increased costs if they were forced to incur them by the Environmental Protection Agency. The moderating competitive effect, lower cost barge transportation, would be a non-factor given that waterway traffic would have increased past the capacity of the lock network. This being the case, option one produces results that are no different than option two. Society would pay the pollution abatement cost under each alternative. We would thus recommend removing option one from the report or provide a theoretical justification for leaving the material in the document.

Response: Placing a value on incremental emissions is a difficult task. Hopefully, the discussion of alternative pollution damage assessment techniques is a useful part of the study. I do not think that the two approaches which I discuss in the study are necessarily the only possible ones. There may be other valid assumptions or models of how railroads would react to increased emissions. I agree with the reviewers that the most likely scenario is that society will incur the cost of increased emissions. However, the social cost may be much different if railroads pass the incremental pollution control cost on to shippers in the form of higher rates, than if the incremental emissions are unabated and result in human and environmental damage. In essence, the incremental cost of pollution abatement (whether paid by railroads or shippers) may be less than the damage to humans and the environment that would result if the incremental emissions are not abated. This difference in perspectives is one of the primary reasons that I approached the analysis as I did. Finally, as I stated in the report, more thought and discussion of alternative approaches are needed.

Necessary Assumptions

Dr. Tolliver makes three basic assumptions which allow the completion of the study in a limited time period. First, rail transportation is the only feasible alternative to barge transportation. Second, rail distances are the same as water distances for non-grain traffic. Third, any gathering or distribution movements by truck at origin or destination are excluded from the analysis. These assumptions, which may in some circumstances yield benign results, are not necessary given that the sample of ultimate origins and destinations used in the upper Mississippi River and Illinois Waterway study are available from TVA in Arc View (Geographic Information System-GIS) format. Most likely the assumptions do make a difference in the analysis and should be revisited with the actual GIS database. This is discussed below.

Movement to the Waterway

Page 2 of the text suggests that truck movements used to "gather" grain were excluded from the analysis. We need some clarification on this issue. Does this mean that all truck / rail movements to barge loading points were excluded or simply truck movements from farm to elevator? It is well known that some of the grain shipped by barge moves a considerable distance to the river either by truck or rail. If, in fact, the analysis excludes these route segments, it almost certainly overstates the efficiency of the navigation alternative. On the other hand, if this statement simply refers to truck movements from the farm, then little harm would be done.

Response: *The analysis did not consider truck movements prior to or subsequent to a water or rail movement, at origin or destination. The purpose of the study was to directly compare the line-haul fuel efficiencies of rail and barge. I also did not consider energy consumed in loading and unloading cargoes, operating gates, drawbridges, traffic control devices, etc.*

*The traffic forecasts provided to me by the USACE were aggregated by origin state. The forecasts were for 2015, 2030, and 2050. I was not asked by the UASCE to develop new traffic forecasts but to estimate the energy, emission, and safety effects associated with **their** forecasts. The findings of my report should be interpreted as relating only to those traffic forecasts provided by the USACE (from origin regions to destination regions) in the "with project" and "without project" scenarios.*

St. Louis Alternative

In preparing the rate information for the Rock Island District, TVA included a "St. Louis" alternative whereby grain moved by rail or truck for transloading to barge at St. Louis. Our recollection is that the St. Louis alternative dominated an all-land routing in about 40% of the cases. We are unable to discern whether or not this routing was considered within Dr. Tolliver's analysis. Again, if it was not, the results may overstate navigation's efficiency.

Response: *As stated above, the traffic forecasts were provided to me by USACE. They were aggregated by origin state and destination region. The forecasts were for 2015, 2030, and 2050. The findings of my report should be interpreted as relating only to the traffic forecasts provided by USACE for the "with project" and "without project" scenarios.*

Approach to Energy Efficiency Analysis

Dr. Tolliver assumes that barge and rail fuel efficiencies will increase during the study period and that the relationship between the two carriers will remain the same throughout the study period. Fuel efficiency in the study is a pure function of technology.

This assumption incorporates the notion of an inelastic elasticity of substitution between labor and fuel in the towing industry and, as a result, probably contributes to an underestimation of longer-term efficiency. TVA, Marshall, and the St. Louis District have discussed with Rock Island economists the notion that the towing industry on the upper Mississippi River and Illinois Waterway is substituting fuel for labor and are thus using towboats with more horsepower than is necessary for moving cargo and empty barges on these two waterways. The lower horsepower boats are now used to move tows downstream on the lower Mississippi River which then return the empty barges upstream via the Tennessee Tombigbee Waterway. This manner of operation is a direct result of the low level of real diesel fuel prices. Real diesel fuel prices during the period 1978-1997 are shown in the attached figure (not included). Note that real prices in 1997 were about 1.5 times lower than at their peak in the early 1980's. It is unlikely that this relationship will continue given market conditions in relation to the supply of petroleum. It is more likely that there will be a continual rise in real energy prices.

Higher diesel fuel prices would impact towing industry efficiency in two ways. First, we strongly suspect that commercial navigation's fuel efficiency would have been greater during a time of more average fuel prices. Smaller horsepower boats would have yielded greater efficiency. Second, higher fuel prices provide opportunities for existing shippers to expand their use of the waterway and for new users to use creative backhaul options. Both lower horsepower boats and higher barge utilization would yield greater towboat efficiency. Certainly, Dr. Tolliver had no means of either identifying or adjusting for this pattern of fuel usage. In fact, it appears he may have relied heavily on some of our previous work in developing consumption rates. Nonetheless, this is one area of analysis that TVA and Marshall University have been looking at for possibly incorporating into any new comprehensive study of energy efficiency on the Upper Mississippi River and Illinois Waterway. Scenario analysis seems appropriate here.

Response: The reviewers' comments should be considered by readers when interpreting the findings of my study. The barge fuel consumption factors that I used were for a very short-run period and may have reflected managers' decisions to optimize factor inputs without consideration to external or environmental costs. This practice may cause barges to appear to be less-fuel efficient than is theoretically possible. However, the substitution of fuel for labor by barge operators would be reflected in the modal cost comparisons. It is unclear how these substitutions and tradeoffs might affect NED benefits, overall. A more in-depth analysis of alternative approaches would be useful. In the report, I discuss "theoretically-efficient" revenue ton-mile per gallon estimates that were developed by Jeffery Marmorstein. It might be useful in a follow-up study to simulate how the use of theoretically-efficient waterway fuel consumption factors would affect modal comparisons.

Routings and Emission Damages

The analysis (Page 37) assumes that 90% of rail routings traverse rural rather than urban settings. While we wouldn't necessarily quibble with this assumption, it would be altogether unnecessary were it possible to actually route the movements and utilize associated population densities to evaluate exposure. This is the course taken in the latest round of Ohio Basin work. The results, so far, are very encouraging.

Concerning the issue of impacts on non-attainment areas, the report (page vi) notes the STB threshold for an environmental impact statement to be completed. Earlier research (Burton) has indicated that area railroads may be able to add the capacity to handle the diverted tonnage through small-scale network improvements which would make an EIS unnecessary. Additionally, the report notes the potential impacts on nonattainment areas given significant diversions to rail transportation. As the map shows (not included), grain traffic moving to New Orleans must traverse St. Louis, Memphis, and New Orleans, all of which have attainment problems. In this particular movement, Litchfield, Illinois to Westwego, Louisiana, the diversion to rail transportation bypasses Memphis but does traverse Birmingham which also has compliance problems. In fact, the truck-barge routing accounts for 312 miles through Metropolitan Statistical Areas as compared to the rail routing of 309 miles. To treat adequately the air pollution implications of potential traffic diversions, each movement would have to be examined within the context of exact routings which would require significant resources. In the above example, there would be limited, if any, environmental benefits of barge transportation. This process requires significant temporal and financial resources – resources which

I'm sure were unavailable to Dr. Tolliver who was forced to make some strong assumptions to complete his study.

Class 1 Railroads
Of concern is the assumption that only Class 1 railroads would originate traffic in the study area. In fact, only 62 percent of the Iowa rail corn movements (STB 1997) moved on class 1 railroads and 38 percent originated on regional or short line carriers. Of greater concern is the assumption of assigning a specific class 1 carrier to a specific state when the actual rail routings are available. In the same vein, using actual rail routings includes rail circuity given the dominance of the Union Pacific Railroad in the Gulf export market.

Response*: Because the traffic forecasts were for origin states or regions, some assignment of future traffic to specific railroads was necessary in order to estimate rail fuel consumption. However, I believe that the assignments described in the report are reasonable.*

Most of the incremental traffic is projected to move long distances to the Pacific Northwest, Gulf Ports, or other destinations in the without-project scenario. Short-line railroads usually haul traffic for very short distances before interchanging the traffic with Class I railroads for the long-haul movement. From a fuel consumption perspective, any short-line movement prior to or subsequent to a Class I movement would not have an appreciable effect on the report's conclusions.

In the study, non-unit train shipments were assumed to move some distance in way trains. Class I way trains are very similar to short-line railroad operations. Way trains are relatively small trains that move short distances at slow speeds, experiencing frequent acceleration- deceleration cycles. Class I railroads tend to use older, lower-horsepower locomotives on many way trains. In many cases, these units are similar to the power used by short lines. In summary, I don't think that the assignment of entire movements to Class I carriers (instead of assigning a brief portion of some movements to short-line railroads) has a significant effect of the report's findings.

Theoretical Long Distances
An additional concern is the development of theoretical long distance routes to California and Texas. Each of these alternatives is a "Trojan Horse" in that actual STB Waybill data show the California destinations to be either flour mills or turkey feed lots that only receive single or multi-car shipments. The actual Texas destinations are border crossings points into Mexico, and these points are limited to single or multi-car movements.

Response*: I used waybill data only to allocate the projected traffic among service levels (e.g., unit train, multi-car, single-car) and to estimate certain model parameters (such as the average net weight and tare weight per car). I did not use waybill data to assign traffic originating in the study area to destination markets. The traffic forecasts provided by the USACE considered the most likely future markets for traffic affected by the proposed alternatives. In the without-project scenario, grain traffic moving to the Pacific Coast was assumed to move to the Pacific Northwest, not to California or Texas.*

Valuation of Emission Damages

We see nothing objectionable in the methodology Dr. Tolliver used to value emission damages. One might argue that highway and off-road damages will be quite different, but the study's approach is, in many ways, reminiscent of some of our earlier efforts to adapt fixed-source damages estimates to the current context. Again, however, while Dr. Tolliver's method is certainly credible, we think there's a significant opportunity to use GIS routings, population densities, and actual exposures to take the analysis to a higher level. In the work Marshall has performed for the Huntington District (also under review at this time), we have attempted to identify location-specific air quality impacts. Hopefully, it may be possible to integrate Dr. Tolliver's method with that currently being developed by Marshall and TVA in order to obtain a hybrid method that is superior to both.

***Response**: I agree with the reviewers' comments. Combining efforts in emission analysis and using GIS-based routings and databases should yield improved hybrid methods.*

Noise Pollution

Dr. Tolliver reviews the highway literature regarding noise pollution but does not have the resources to actually make an abatement estimate. From the review, Dr. Tolliver seems to be leaning toward a dollars per decibel per household parameter estimated by the Federal Highway Administration for use in highway studies. Using the median housing value from the 1993 Census survey, annualized at a 10 % discount rate and multiplied by 0.4%, FHWA estimated a highway noise cost of about $35 per decibel per housing unit.

The problem with using highway data to estimate rail impacts stems from the fact that highway noise is a low drone that is close to the ground. Rail horn noise impacts more people than does track noise and is intermittent from a source that can be about 20 feet off of the ground (12 feet on the locomotive and another six when the bed is raised). The limitation of applying these data to towboat operation seems to be twofold. First, $35 per decibel seems too low (both to us and a TDOT Environmental Engineer) given the $25,000 that the State of Tennessee Department of Transportation is allocating now per residence for abatement of highway noise. At $35 per decibel per household, the dollar value should be around $1,800. Second, it seems that railway horn noise would penetrate further into the community and would affect property values at a greater distance from the source than would be expected from highway noise. This topic probably needs further research most likely in the area of Hedonic price indices.

Response: *I agree with the reviewers' comments. In the report, I stated that railroad and highway noises are different. I only used the FHWA data to illustrate the effect of a one decibel increase in transportation noise on housing values in urban areas. I would not recommend using this value to estimate railway noise impacts until (and if) more detailed studies have verified its applicability.*

General Conclusions

Given the temporal and financial resources available, Dr. Tolliver has prepared a thorough and reasonably defensible assessment of the fuel, emission, and pollution abatement differentials that might be predicted under the various "with" and "without project" conditions. If our concerns over the movement to the waterway and inclusion of the St. Louis alternative are borne out, it might be desirable to modify the current estimates accordingly, but this would seem to entail only a modest amount of additional effort. Additionally, the theoretical justification for assuming that railroads would internalize cost should be laid out.

Recommendations

More generally, this work, in combination with the efforts at TVA, Marshall, and elsewhere, seems to point to a need for cooperation within the context of a more comprehensive, adequately funded study. Each entity currently engaged in fuel and emissions research appears to have expertise to contribute, but it also seems that a great deal of effort is being spent reinventing existing (or even obsolete) methodologies or reconciling results that differ because of methodological inconsistencies. We thus feel that the best use of scarce navigation development funds would be to focus on a comprehensive and coordinated study which would include Dr. Tolliver's work. To this end, we would not recommend funding Dr. Tolliver to make extensive changes to his draft document that would incorporate our comments.

[1] Marmorstein, Jeffrey. An Analysis of Air Quality Impacts Resulting From Potential Actions On The Upper Mississippi River – Illinois Waterway Navigation System, U.S. Army Corps of Engineers, September, 1999.
[2] Marmorstein, Jeffrey. An Analysis of Air Quality Impacts Resulting From Potential Actions On The Upper Mississippi River – Illinois Waterway Navigation System, U.S. Army Corps of Engineers, September, 1999.
[3] The term TOFC , as used in this report, encompasses container-on-flatcar (COFC) shipments on traditional flatcars. Double-stack container cars are considered as a separate category for purposes of energy analysis.
[4] Based on a personal telephone interview with Dr. Mark Burton.
[5] Inconsistencies are readily apparent when a data field is the sum or difference of other accounts. In stable periods, some activity measures can be cross-referenced. For example, car miles in year *t* should approximately equal the carloads handled in year *t* times the average length of haul in year *t-1*.
[6] Choosing a significance level in advance is a way of placing limits on the risk of reaching a wrong conclusion. For example, a significance level of 5% means that if you collected 100 samples and performed 100 hypothesis tests on b_0 or b_1, you would expect to reject a true null hypothesis about five times. Rejection of a true null hypothesis is referred to as a Type I error. The probability of a Type I error is called alpha, and is computed as the level of significance divided by 100. As the level of significance increases (i.e. as " gets smaller), the probability of incorrectly rejecting a true null hypothesis (i.e. committing a Type I error) decreases. However, the probability of *not* rejecting a false null hypothesis increases. Failure to reject a false null hypothesis is referred to as a Type II error. Fortunately, the probability of a Type II error decreases as the ratio of the sample size to the population increases The importance of the significance level is illustrated by the following example. Suppose the p-value for b_1 is 0.03. If a 5% level of significance had been chosen in advance(i.e. an " of 0.05), then the null hypothesis would be rejected. Alternatively, if a significance level of 1% had been chosen in advance, then the null hypothesis would not be rejected.
[7] . Although the net tons are unknown for each train type, they can be estimated using the average tare tons per car for each railroad. This calculation assumes that the tare weights of cars used in all types of train service are similar. The estimates may be biased if the mean tare weight varies among types of trains. However, the direction of potential bias cannot be predicted in advance.
[8] An overall weighted mean is computed for each railroad by multiplying the predicted RTMG value in a given type of train service by the percent of GTMC in that train class. The weighted mean is then compared to each railroad's *actual* value.
[9] There many possible explanations for the higher errors for Soo Line and KCS. Most likely the errors are the result of variations in gross-to-net ratios among trains and definitional issues regarding train service. In some respects, the distinctions between through and way train service may be blurry. Such definitional issues may be more pronounced for certain railroads because of short hauls and route configurations.
[10] Association of American Railroads. *AAR Railroad Facts: 1999 Edition.*
[11] Paraphrased from: United States Environmental Protection Agency, Office of Air and Radiation, Regulatory Update: EPA's Nonroad Engine Emissions Control Programs, EPA420-F-99-001, January 1999.
[12] Paraphrased from: United States Environmental Protection Agency, Office of Air and Radiation, Regulatory Update: EPA's Nonroad Engine Emissions Control Programs, EPA420-F-99-001, January 1999.
[13] United States Environmental Protection Agency, Office of Air and Radiation, Regulatory Update: EPA's Nonroad Engine Emissions Control Programs, EPA420-F-99-001, January 1999.

[14]U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Policy. *The Benefits and Costs of the Clean Air Act 1990 to 2010: EPA Report to Congress*, November 1999.
[15]See Table A-9 in Appendix A of the aforementioned study.
[16]See Table B-12 in Appendix B of the aforementioned study.
[17] U.S. Department of Transportation, Federal Highway Administration. Highway Economic Requirements System: Technical Report, Version 3.1, March, 1999.
[18] McCubbin, D. and M. Delucchi. Health Effects of Motor Vehicle Air Pollution, Institute for

Transportation Studies, University of California, Davis, 1996.
[19]University of Memphis, Transportation Studies Institute. *Accidents and Hazardous Spills Analysis for Upper Mississippi River Basin*, Prepared for U.S. Army Corps of Engineers, Rock Island District, September 1998.
[20]Transportation Research and Analysis Center. *Upper Mississippi River - Illinois Waterway System Navigation - Accidents and Hazardous Spills Task, Final Report*, Prepared for the U.S. Army Corps of Engineers, Rock Island District August 1996.
[21] For example, the estimated economic cost of a fatality in 1998 varied by less than 8 percent between the motor vehicle and work environments.
[22] This description of comprehensive costs is paraphrased from: *Injury Facts, 1999 Edition*, National Safety Council.
[23] The administrative cost of motor-vehicle insurance is estimated as the difference between premiums earned (adjusted to remove fire, theft, and casualty premiums) and pure losses incurred. Legal expenses include court costs, and plaintiff's and defendant's time and expenses.
[24] U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning, Noise and Air Quality Branch. Highway Traffic Noise Analysis and Abatement Policy and Guidance, Washington, D.C., June 1995.
[25] Ibid.
[26] U. S. Department of Transportation, Federal Railroad Administration. High-Speed Ground Transportation Noise and Vibration Impact Assessment, Washington, D.C., December 1998.
[27] U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning, Noise and Air Quality Branch. Highway Traffic Noise Analysis and Abatement Policy and Guidance, Washington, D.C., June 1995.
[28] Ibid.
[29] Ibid.
[30] U. S. Department of Transportation, Federal Railroad Administration. High-Speed Ground Transportation Noise and Vibration Impact Assessment, Washington, D.C., December 1998.
[31] J. Edwards; *Transportation Planning Handbook*; Institute of Transportation Engineers; Prentice Hall, Englewood Cliffs, New Jersey; 1992.
[32] U.S. Department of Transportation, Federal Highway Administration. 1997 Federal Highway Cost Allocation Study, Appendix E: Non-Agency Costs of Highway Transportation. Unpublished draft report.
[33] U.S. Department of Transportation, Federal Highway Administration. 1997 Federal Highway Cost Allocation Study, Appendix E: Non-Agency Costs of Highway Transportation. Unpublished draft report.
[34] After: Hanson, C.E. and L.E. Wittig. *Prediction of Wayside Railroad Noise*, Transportation Environmental Review Process, Transportation Research Record 580, Transportation Research Board, Washington, D.C., 1976. Revised by author to include L_{dn} measurement.
[35] Environmental Protection Agency, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, Washington DC, March 1974.
[36] General Accounting Office (GAO). Transportation Noise: Federal Control and Abatement Responsibilities May Need to be Revised, Resources, Community and Economic Development Division; October 1989.
[37] U. S. Department of Transportation, Federal Railroad Administration. High-Speed Ground Transportation Noise and Vibration Impact Assessment, Washington, D.C., December 1998.
[38] U.S. Department of Housing and Urban Development, "Environmental Criteria and Standards", 24 Code of Federal Regulations Part 51, 12 July 1979; amended by 49 FR 880, 6 January 1984.
[39] U.S. Department of Transportation, Federal Aviation Administration, "Federal Aviation Regulations Part 150: Airport Noise Compatibility Planning," January 1981.
[40] U.S. Department of Transportation, Federal Highway Administration. 1997 Federal Highway Cost Allocation Study, Appendix E: Non-Agency Costs of Highway Transportation. Unpublished draft report.
[41] P. Nelson; *Highway Noise and Property Values: A Survey of Recent Evidence*; Journal of Transportation Economics and Policy; May 1982.
[42] U.S. Department of Transportation, Federal Highway Administration. 1997 Federal Highway Cost Allocation Study, Appendix E: Non-Agency Costs of Highway Transportation. Unpublished draft report.

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[43] U. S. Department of Transportation, Federal Railroad Administration. *Draft Environmental Impact Statement*. Proposed Rule for the Use of Locomotive Horns at Highway-Rail Grade Crossings. December 1999.

[44] In these studies, FRA concluded that a maximum horn sound level of 104 dBA would reduce community horn noise exposure by approximately 25 percent on average. A day/night variable sound level of 111 dBA during the day and 104 dBA during the night was found to be effective in reducing community noise impacts by approximately 15 percent. FRA also estimates that moving all locomotive horns to the front could reduce the selected maximum sound level noise exposure as much as a 35 percent.

[45] U. S. Department of Transportation, Federal Railroad Administration. *Draft Environmental Impact Statement*. Proposed Rule for the Use of Locomotive Horns at Highway-Rail Grade Crossings. December 1999.

[46] 49 CFR 1105.7 (4)

[47] 49 CFR 1105.7 (5)

[48] 49 CFR 1105.7 (5)

[49] 49 CFR 1105.7 (6)

[50]Short Elliott Hendrickson Inc. *Southern Minnesota Rail Corridor Safety Plan - Draft*, prepared for Minnesota Department of Transportation, January 2000.